UNCLASSIFIED

LABORATORY STUDIES OF THE ABILITY OF OBSERVERS TO PERFORM THREE VISUAL TASKS REQUIRED OF PILOTS IN APPROACH AND LANDING

W. S. Vaughan, Jr.
Wallace F. Rollins
Terrence S. Luce

HSR-RR-63/7-Mk-X

April 1963

Prepared Under:

Contract No. FAA/BRD-401

Systems Research and Development Service
Federal Aviation Agency
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard
Arlington 1, Virginia

HSR

human sciences research inc

WESTGATE INDUSTRIAL PARK
POST OFFICE DRAWER 370 McLEAN, VIRGINIA

LABORATORY STUDIES OF THE ABILITY OF OBSERVERS TO PERFORM THREE VISUAL TASKS REQUIRED OF PILOTS IN APPROACH AND LANDING

W. S. Vaughan, Jr.
Wallace F. Rollins
Terrence S. Luce

HSR-RR-63/7-Mk-X

April 1963

"This report has been prepared by Human Sciences Research, Inc. for the Systems Research and Development Service (formerly Bureau of Research and Development), Federal Aviation Agency, under Contract No. FAA/BRD-401. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA."

ACKNOWLEDGMENTS

The purpose of this laboratory work was to describe the ability of human observers to perform three visual tasks representative of those required of pilots conducting a final approach. The type of information provided by studies of this kind can be used to specify optimum values for lighting pattern elements and to reduce the number of lighting alternatives for simulator or field evaluation.

The authors acknowledge the support of Dr. R. K. McKelvey, Chief, Human Factors Branch, Research Division, Federal Aviation Agency. Dr. McKelvey has pioneered in the efforts to supplement FAA flight test facilities with simulator and laboratory facilities. We appreciate his encouragement of our work and his early recognition of the need for human factors information to guide the design of marking and lighting systems.

The authors also thank Mr. Roger B. Frey, now Assistant Professor of Psychology at the University of Maine and Mr. Thomas R. Virnelson, Research Engineer at HSR for their several contributions including design of the laboratory apparatus and their ideas re: data collection, recording, and analysis.

Mrs. Rose Anna Betts and Mrs. Bette Listman typed and managed the production of the report.

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard, Arlington 1, Virginia
LABORATORY STUDIES OF THE ABILITY OF OBSERVERS TO PERFORM THREE VISUAL TASKS REQUIRED OF PILOTS IN APPROACH AND LANDING
W. S. Vaughan, Jr., Wallace F. Rollins, and Terrence S. Luce, April 1963
18 pp., includ. 4 illus., Final Report
(Contract FAA/BRD-401, Project No. 424-2R)

ABSTRACT

A series of laboratory studies was conducted to describe the ability of adult human subjects to perform visual tasks representative of those performed by pilots during final approach and landing. Ability to perform visual tasks was related to variations in lighting design parameters. Results of these studies can be used as preliminary design guides for airport and heliport lighting systems. The present studies should be expanded to include dynamic conditions and results should be validated under operational flight conditions.

Performance in three visual tasks was studied in relation to lighting design variations. Judgment of vertical displacement was related to variations in geometric shape and to amount of separation between a pair of point sources. Judgment of lateral displacement was related to length of a solid line and interval of separation between two point sources where the stimuli were oriented colinear with the line of sight. Judgment of rotation from a horizontal orientation was related to length of line and interval of separation between two point sources where the stimuli were oriented perpendicular to the line of sight.

The stimuli, geometric forms, solid light bars and separated point sources, were constructed of lengths of string, wire, and round-headed map pins which were painted with yellow ultraviolet paint and

mounted on boards. The stimulus boards were covered with black felt and the experimental room was completely darkened except for a 15-watt ultraviolet bulb baffled so as to illuminate only the stimulus. Stimulus lengths and separation intervals were measured in inches, then translated to minutes of visual angle as a more general description of the variable. The performance measure used throughout all experiments as an operational index of ability to perform the visual tasks was variability of the subjects' responses.

Preliminary design recommendations resulting from the experiments are as follows:

> Geometric forms which are of equivalent perimeter and whose front and back borders are separated by an equivalent distance provide equivalent cues to slant and therefore to vertical displacement.
>
> Two point sources of light separated by a distance equal to that separating the front and back borders of a geometric pattern provide cues to slant equivalent to those provided by the total pattern.
>
> To provide cues to vertical displacement, the optimal separation between point sources is approximately 9-49 minutes of visual angle.
>
> To provide cues to lateral displacement from a desired line-of-flight, a solid line colinear with the desired line-of-flight should be at least as long as required to subtend 18 minutes of visual angle.
>
> To provide lateral displacement guidance, two point sources should be separated by at least 9 minutes of visual angle and may be separated by as much as 120 minutes.
>
> To provide a horizontal reference, the minimum length of a solid line should be approximately 132 minutes of visual angle.
>
> To provide a horizontal reference, two point sources should be separated by approximately 220 minutes of visual angle, but not more than approximately 440 minutes.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES AND FIGURES

LABORATORY STUDIES OF THE ABILITY OF OBSERVERS TO PERFORM THREE VISUAL TASKS REQUIRED OF PILOTS IN APPROACH AND LANDING

I. Introduction

Problem Area and Research Purpose

The systematic search for an optimal arrangement of airport lights from which pilots can most easily obtain cues necessary to control aircraft in the terminal flight phases was initiated at Arcata Landing Aids Experiment Station in 1946. Several marking and lighting systems were installed and flight tested under low visibility conditions. The search has proceeded to the present day by essentially similar techniques: the installation of an experimental lighting system at a test facility, trial flights by a few pilots, and a qualitative evaluation of the systems by the test pilots.[1] More recently, a visual attachment and flight simulator has been used at National Aviation Facilities Experimental Center to evaluate alternative runway lighting designs (McKelvey, Brown, & Ontiveros, 1961a and 1961b) and to determine optimal spacing between lights in a runway pattern (McKelvey & Ontiveros, 1961).

The search for an optimal lighting pattern for heliports has not yet begun in earnest. Until recently, heliport lighting has not been a critical operational problem since commercial helicopter operations have been limited to good visibility conditions and visual flight. With the development of airborne instrument flight equipment and therefore the imminence of IFR helicopter operations, the visual landing aids problem will begin to receive

---

[1] For reviews of operational test results and methods from 1946 to 1961 see Lybrand, Vaughan, & Robinson, 1959; and Vaughan, Luce, & Kassebaum, 1962.

emphasis. A 1961 review of the state-of-the-art in heliport marking and lighting reveals a wide variety of designs and a minimum of evaluative information (Virnelson & Vaughan, 1961).

One of the major problems in the search for an optimal heliport or airport lighting design is the lack of human factors information which could be used to restrict the range of reasonable lighting alternatives. Currently, any design which is feasible from an engineering point of view and acceptable in terms of a cost criterion becomes a candidate for evaluation in a field installation or flight simulator. These are expensive procedures and the number of possible combinations of designs, colors, spacings, etc. for an integrated airport or heliport lighting system is practically limitless.

Since the function of lighting designs is to provide the pilot with visual cues on which to base control decisions, information about the ability of adult human observers to perform visual tasks involved in critical flight phases is potentially a principal source of lighting design guidance. The search for an optimal lighting solution or, as is the more likely case, the identification of the range of equivalently good designs should be simplified by a catalogue of data relating performance in visual tasks to variations in lighting design variables such as color, spacing, etc. With these kinds of data available, proposed designs could be evaluated and screened prior to expensive simulator or field testing.

A comprehensive approach to the accumulation of this kind of human factors information would include four steps as follows:

1. Identification of <u>control tasks</u> required of pilots in the flight phases for which lighting systems are proposed as aids (primarily approach and landing).
2. Identification of the <u>information</u> required by the pilot as a base for control decisions and identification of <u>visual tasks</u> required to obtain the necessary information

3. Identification of lighting variables (color, spacing, etc) which affect the ability of pilots to perform the visual task.
4. Quantitative description of the relationships between lighting pattern variations and performance in visual tasks.

The series of experiments reported here is a modest beginning toward a human factors handbook of information for airport and heliport lighting designers which could result from comprehensive implementation of the above four steps. Three pilot control tasks critical to successful conduct of a final approach and landing were selected. Information requirements of those control tasks were derived from the flight parameters to be controlled. The visual task implied by the one static information requirement in each control task was selected as the performance variable to be measured. A lighting design element typically used to provide this kind of information was chosen as the stimulus condition and systematically varied through a selected range of values. The selected tasks and lighting design variables are presented in Table 1.

Experimental Approach and Assumptions

The research model used in each experiment was the Method of Average Error or, as it is sometimes named, The Method of Adjustment (Guilford 1954). The basic procedure of this method requires the subject to manipulate a stimulus so as to match a standard stimulus. Therefore, in the experiments relating judgment of vertical displacement to type of geometric form, a standard degree of slant was set with one stimulus board and the subject matched this degree of slant with another. In the experiments relating judgment of alignment to length of a linear stimulus, the subject aligned himself with the direction of the line; and in the experiments relating judgment of horizontal orientation to length of linear stimuli, subjects adjusted a stimulus board until satisfied that the stimulus was horizontal.

TABLE 1

Selected Visual Tasks and Lighting Design Elements Studied

Pilot Control Tasks	Information Required About Flight Parameters	Visual Tasks Selected for Study	Sources of Information	Design Variables Studied
Establish and maintain constant a fixed angle of descent (glide slope)	Vertical displacement (Δz) Velocity of vertical displacement (dz/dt) Acceleration of vertical displacement (d^2z/dt^2)	Judgment of vertical displacement from reference altitude (Δz)	Perspective change in shape of geometric forms	Type of geometric form Rectangle Circle Triangle Square Hexagon Trapezoid
Establish and maintain alignment with a desired line-of-flight	Lateral displacement (Δx) Velocity of lateral displacement (dx/dt) Acceleration of lateral displacement (d^2x/dt^2)	Judgment of lateral displacement from reference line-of-flight (Δx)	Alignment with: an imaginary line through two point sources a solid bar	Length of solid bar 2.7, 4.5, 9.1, 18.1, 36.2, 60.3 minutes of visual angle. Interval separating two point sources 2.7, 4.5, 9.1, 18.1, 36.2, 60.3, 120.6 minutes of visual angle
Establish and maintain a level roll attitude	Rotation about y axis (Θy) Velocity of rotation about y axis ($d\Theta y/dt$) Acceleration of rotation about y axis ($d^2\Theta y/dt$)	Judgment of rotation from horizontal orientation (Θy)	Orientation of: an imaginary line through two point sources a solid bar	Length of solid bar 11.0, 16.6, 33.3, 66.4, 132.6, 221.4, 442.0 minutes of visual angle Interval separating two point sources 11.0, 16.6, 33.3, 66.4, 132.6, 221.4, 442.0 minutes of visual angle

The results of each experiment, therefore, are in the form of functional relationships between variations in some aspect of a lighting design and a measure of the subjects' ability to perform a visual task. In the experiments on judgment of vertical displacement, the stimulus variables were type of geometric form and extent of separation between pairs of point sources. The criterion measure was variability in subjects' ability to match the angle of slant of the geometric forms and the pairs of lights. In the experiments on judgment of lateral displacement, the stimuli were straight lines of various lengths and a pair of point sources separated by a range of distances. The subject's task was to align himself with the direction of the line or the imaginary line connecting the pair of points. Performance was, therefore, related to length of line and to separation between point sources. In the experiments on judgment of rotation from horizontal orientation, the stimuli were lines and pairs of point sources and the performance measure was variability in subjects' ability to adjust the stimulus to a horizontal orientation. Performance variability was described as a function of line length and of separation between point sources.

Generalization of these results to pilot performance requires the assumption that ability to perform the laboratory tasks involves the same visual-perceptual processes as are contained in the pilot's visual tasks. Subjects in the experiments were non-pilot, adult men and women. To generalize results of the studies to pilots, therefore, requires the assumption that the visual perceptual processes of pilots are not significantly different from those of other adults.

Support for these assumptions requires a program of validation studies in the specific visual task areas. One study has been conducted, however, in which a similar psychophysical method was used in a laboratory setting and validated in the field (Day, Baxter, Lane 1961).

In this study, a 1 to 1000 scale model of a light bar alignment system (PVG) for providing pilots with angle of approach information was constructed. A laboratory study of misalignment thresholds was conducted with both pilot and non-pilot samples as subjects. A similar type of study was then carried out in a field setting where subjects viewed an operational PVG installation from a range of seven miles. There were no statistically significant differences in misalignment thresholds from laboratory to field situations for pilots or for non-pilots. Non-pilots appeared to have lower misalignment thresholds than pilots (39 vs. 54 seconds of visual angle) although this difference may be a function of different instructions. In essence, non-pilots were asked to report "aligned" or "misaligned", while pilots were asked whether or not the difference was sufficiently large to require corrective control action.

II. Summary of Experiments

Judgment of Vertical Displacement

Background

One of the more difficult control tasks involved in final approach and landing is to track a desired glide slope. Fixed wing commercial aircraft typically are required to fly a 2.5° angle of approach on instrument landings. Helicopter approach angles vary with conditions such as air temperature, gross weight, and the terrain obstacles surrounding the heliport. Typical angles of approach, however, are in a range between 8-45°. In either fixed-wing or rotary-wing approaches, a desired glide angle is indicated and the pilot's task is to establish this angle and maintain it at a constant value throughout the approach.

Information requirements involved in this control task are indications of vertical acceleration, velocity, and displacement from a desired altitude through time. The visual task selected for study was the judgment of vertical displacement. One of the sources of information for this visual task is the perspective change of the runway or heliport boundary lighting pattern. That pattern may be considered optimal which provides the pilot with the most sensitive indication of change of perspective, i.e., the pilot can more quickly notice a displacement in altitude from the desired value.

Previous research on the problem of judging vertical displacement from changes in perspective has provided the conclusion that perceived slant of a geometric form is typically an underestimation of the physical slant angle (Thouless 1931, Spencer 1953, Clark, Smith & Rabe 1955,

Smith 1956). The study by Smith (1956) further indicates that accuracy of estimating slant angle is a function of the degree of slant. Accuracy in estimating slant is improved as the degree of slant increases from perpendicular-to-line-of-sight toward parallel-to-line-of-sight. In this study results also suggest that judgment of slant is more accurate with circles than with rectangles when the slant angle is greater than 30° from the vertical, and that the reverse is true for slant angles less than 30°.

Procedures and Results

Three experiments were conducted. In the first and second experiment, six geometric forms of equal perimeter were used as stimuli: rectangle, circle, square, triangle, hexagon, and trapezoid. The stimuli were constructed of heavy string, painted with yellow ultraviolet paint, and mounted on black-felt-covered stimulus boards. Standard stimulus boards were set at 5, 15, 25, 35, and 55° from the horizontal and the subject's task was to match each standard with a comparison stimuli. The results of both experiments were as follows:

> Ability to estimate slant of any geometric form is a function of degree of slant. Angles closer to perpendicular-to-line-of-sight are less accurately estimated than angles which approach the horizontal.
>
> The six geometric forms are equivalent stimuli with respect to the visual task studied; all contain essentially equivalent cues to slant.

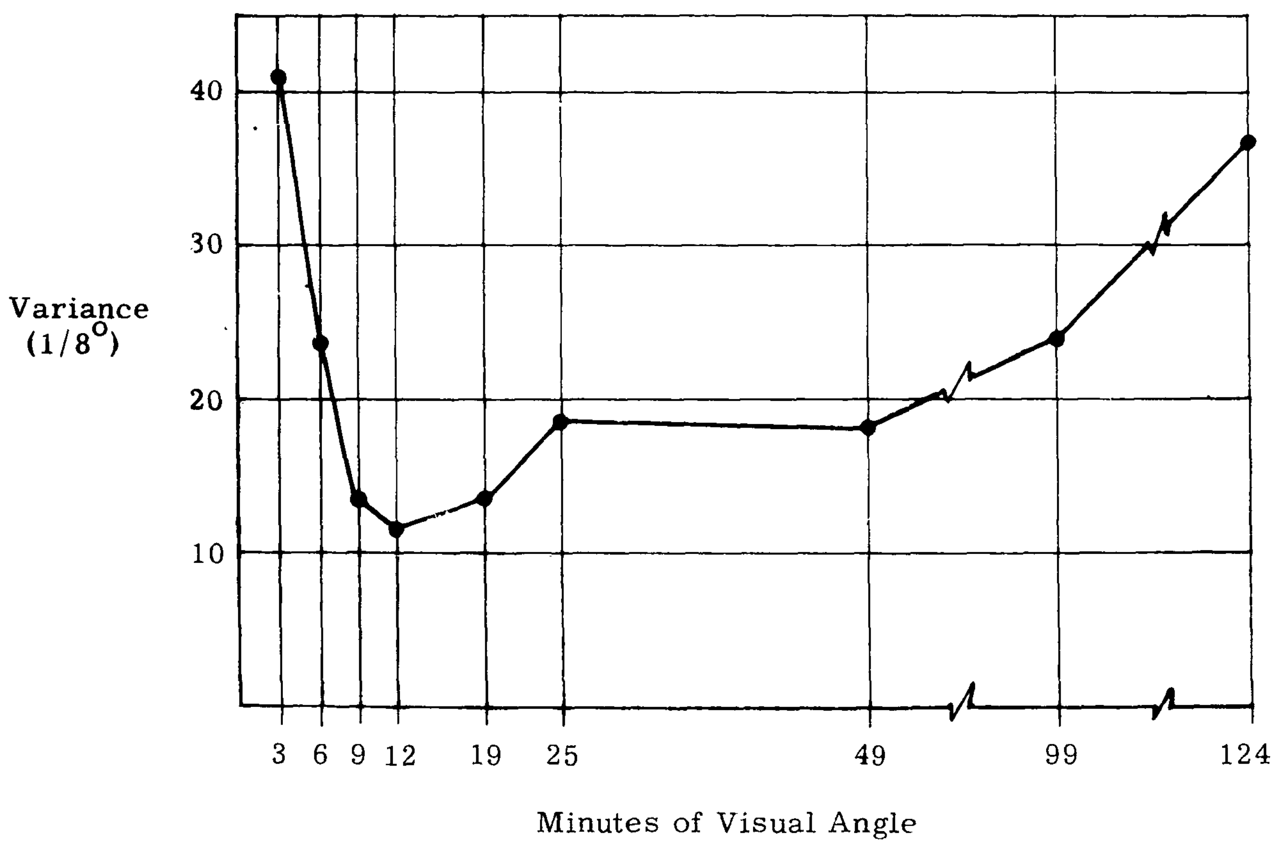
In the third experiment, two aligned point sources, representing top and bottom borders of the geometric forms were used as stimuli. The point sources were round-headed map pins painted with ultraviolet paint and illuminated by a 15-watt ultraviolet bulb. Separation between point sources was the design variable of interest in this experiment and nine separations

were selected: 3, 6, 9, 12, 18, 25, 49, 99, and 124 minutes of visual angle. Stimuli were set at four different slant angles and ability of subjects to match the standard was recorded in $1/8^{o}$ discrepancies.

Performance in this visual task varied as a function of extent of the separation between point sources. Figure 1 is a plot of performance variability as a function of separation. Statistical tests of the differences in performance variability among the separation intervals indicate that separations of 9-49 minutes of visual angle are equally good; separations of less than 9 or greater than 49 are associated with significantly greater performance variability.

FIGURE 1

Response Variability as a Function of Separation
Between Two Point Sources:
Judgment of Slant



Judgment of Lateral Displacement

Background

Another of the pilot's control tasks in approach and landing is to establish and maintain a line-of-flight congruent with a desired line-of-flight. In the case of fixed wing aircraft, the desired line-of-flight is the extended runway centerline; for rotary wing aircraft it is a radial extending downwind from the touchdown zone. Flight parameters to be controlled in this task are acceleration, velocity, and displacement in the lateral plane. The visual task selected for study was detection and correction of lateral displacement. The principal lighting element used to provide pilots with information of this kind is a single line of lights oriented along the desired line-of-flight. Optimal separation between adjacent pairs in the string of lights, however has not been experimentally determined. This lighting design variable, therefore, was selected for study.

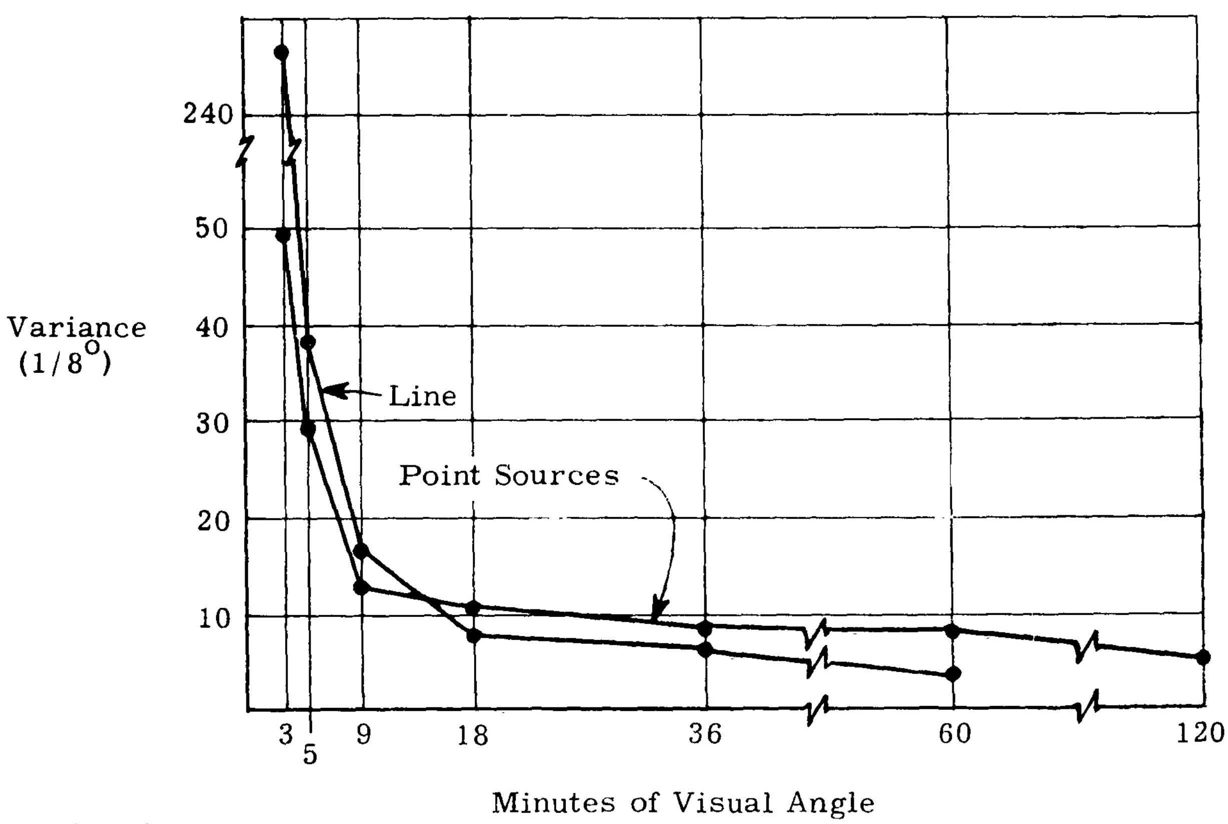
Procedures and Results

Solid bars of various lengths and two point sources separated by various distances were the stimuli. Selected values of length were 3, 5, 9, 18, 36, and 60 minutes of visual angle. Selected values of separation between point sources were 3, 5, 9, 18, 36, 60, and 120 minutes of visual angle. The solid bar stimuli were lengths of 1/8" wire and the point source stimuli were round-headed map pins painted with ultraviolet paint. The stimuli were oriented to randomly selected compass points in the horizontal plane and the subject's task on each trial was to position himself behind a calibrated arc until satisfied that he was aligned with the direction of the light bar or the direction of the imaginary line connecting the two point sources.

Results are illustrated in Figure 2. When solid light bars were used as stimuli, performance variability reached a minimum when the length of the bar was such that a visual angle of 18 minutes of arc was subtended. Further increases in the stimulus length to 60 minutes did not significantly improve or degrade performance.[1] When separated point sources were used as stimuli, performance variability reached a minimum at a separation of 9 minutes of visual angle and remained asymptotic to the limits of the separation interval studied, 120 minutes.

FIGURE 2

Response Variability as a Function of Line Length and Separation Between Two Point Sources: Judgment of Lateral Displacement



[1] These data perhaps explain results of a study by Smith (1962) where line length did not affect ability to estimate angular orientation (heading) of a simulated radar trail. All values of length used by Smith were greater than 18 minutes of visual angle.

Judgment of Rotation from a Horizontal Orientation

Background

Both helicopter and fixed wing aircraft pilots must maintain a level-with-the-horizon roll attitude. The fixed wing pilot is concerned with this control task throughout the approach since a roll deviation will produce an altitude and a heading change. The helicopter pilot is concerned with this task primarily in the late stages of the approach, when he must insure a level descent to avoid ground resonance. This control task requires information about three flight parameters: rotation from a horizontal reference, velocity, and acceleration of rotation. The visual task selected for study was the judgment of rotation from a horizontal orientation. The lighting design elements typically provided as a source of information for this visual task are a solid linear bar or line of lights oriented perpendicular to the line-of-flight. Optimal values for length of a solid line or separation between point source lights, however, have not been determined.

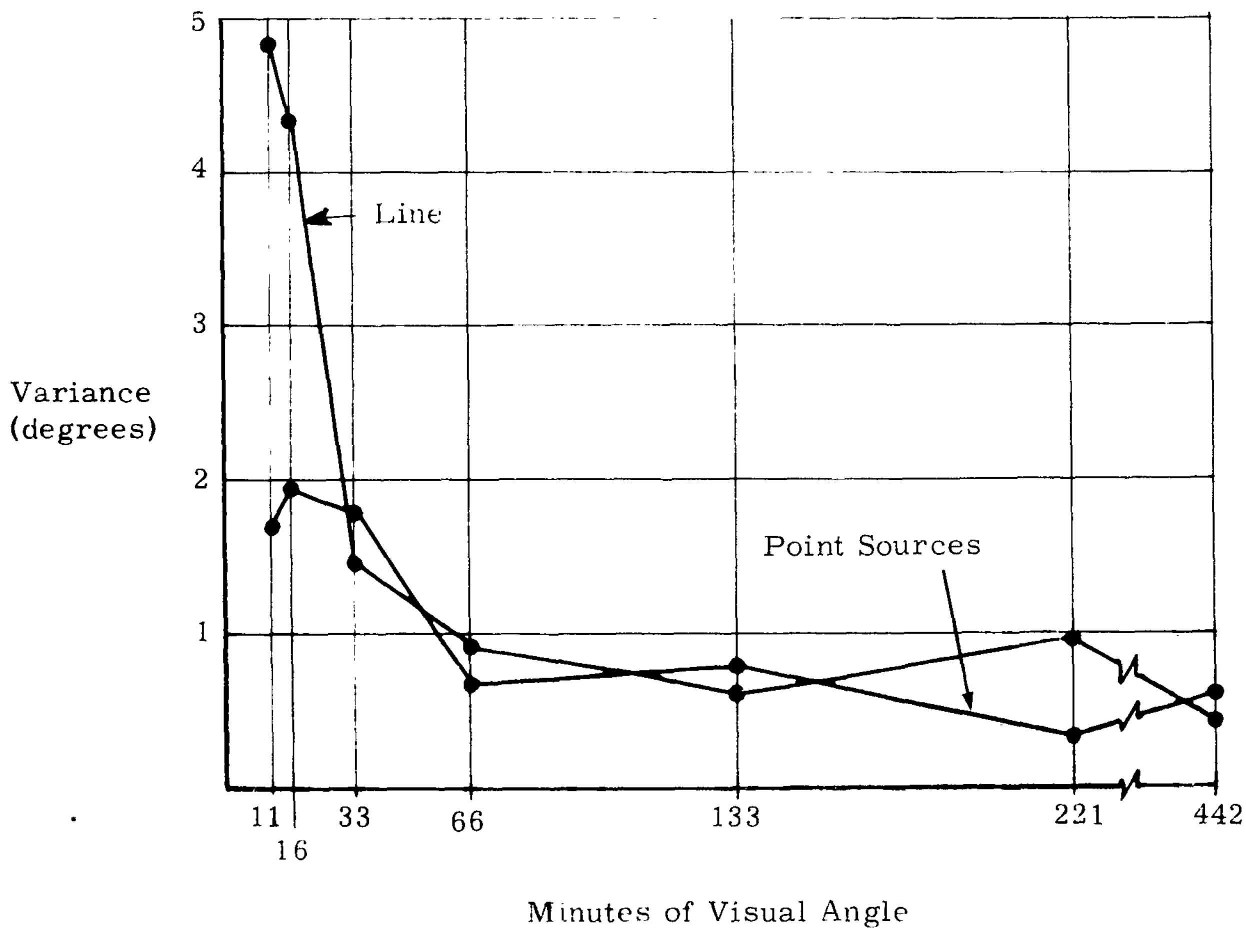
Procedures and Results

Solid lines of the following extents and pairs of point sources separated by identical intervals were used as stimuli: 11, 16, 33, 66, 133, 221, and 442 minutes of visual angle. The stimuli were mounted on a platform which could be rotated about the horizontal axis colinear with the line-of-sight. The platform was offset from the horizontal and the subject's task was to adjust the stimulus back to a horizontal orientation. Variability of settings about the horizontal was used as the measure of performance effectiveness.

Results indicate that performance improves as the length of a solid line is extended from 11 to 133 minutes of visual angle. Beyond 133 minutes to 442 minutes, performance is essentially asymptotic. With separated point sources, performance improves as the interval between the pair of lights is increased from 11 to 221 minutes of visual angle. Beyond this value, performance appears to become more variable. Figure 3 is an illustration of the functions relating performance variability to the lighting design variables: length of line and separation between two source points.

FIGURE 3

Response Variability as a Function of Line Length and Separation Between Two Point Sources: Judgment of Horizontal Orientation



III. Preliminary Design Recommendations

The results of this series of experiments are presented as basic information about the capability of adult human observers to perform selected visual tasks as certain visual stimulus properties are varied in a laboratory environment. The laboratory situation was designed to minimize extraneous information other than the stimulus element studied, and to maximize the sensitivity of the subject's viewing and responding conditions. This was done to insure that variations in subjects' responses were functions of the stimulus variations only and were not confounded with other potential sources of response variation. The data obtained, therefore, are restricted in generality to the conditions of the experiments and particularly by the conditions which differ substantially from the operational case. Some of these conditions include:

a static relationship between viewer and stimulus,

no time pressure on the subject's response,

a stable viewing platform,

no distortions of visual display such as might be introduced by rain, etc.,

no competing or augmenting stimuli other than the light pattern studied.

In only a very limited sense, therefore, can these results be viewed as a basis for operational decisions about how to place lights on an airport or heliport. The results provide baseline information only. This baseline must be modified by the introduction of conditions more representative of the operational situation and by the study of multiple visual tasks in relation to more complicated lighting patterns.

With the above cautions stated, the following operational applications of the results are presented.

Design Guides for Judgment of Vertical Displacement

Given equal perimeter, circle, square, hexagon, triangle, rectangle, and trapezoid provide equivalent cues to slant and, therefore, should be equivalent design alternatives--at least as far as judgment of displacement from a desired altitude is concerned.

A pair of point source lights oriented along the line-of-sight provides as much information about slant as does any of the six geometric forms when the point sources are separated by a distance equivalent to the separation between front and back portions of the complete geometric figure. The important variable for judgment of slant, apparently, is the separation between the point sources.

The pair of point sources (or front and back ends of a pattern) should be separated by at least 9 minutes and no more than 49 minutes of visual angle to provide the most consistent judgments of slant and, therefore, of vertical displacement.

Design Guides for Judgment of Lateral Displacement

Solid light bars should be at least as long as 18 minutes of visual angle to provide an optimal information base for judgment of lateral displacement from a desired line-of-flight.

A pair of point sources provides guidance as effectively as a solid line of a length equal to the separation between the point source lights. To provide optimal guidance, the pair of lights should be separated by at least 9 minutes of visual angle and can be separated by as much as 120 minutes, perhaps more.[1]

[1] 120 minutes of visual angle was the longest separation interval studied and performance continued at an optimal level. It can be expected that increasing the separation will eventually result in performance decrement.

Design Guides for Judgment of Rotation from Horizontal Orientation

A painted line or light bar should be at least as long as required to subtend 133 minutes of visual angle to provide optimal information for judgments of horizontal rotation. Increased length beyond 133 minutes of visual angle provides no improvement in ability to judge horizontal orientation.

A pair of point sources separated by the length required to subtend approximately 221 minutes of visual angle provides optimal guidance for judging horizontal orientation. Degraded performance occurs when the separation is increased to 442 minutes.

IV. References

Clark, W. C., Smith, A. H., & Rabe, A. Retinal gradient of outline as a stimulus for slant. Canad. J. Psychol., 1955, 4, (9), 247-253.

Day, R. H., Baxter, J. R., & Lane, J. C. The psychophysical testing of an aircraft visual approach aid. Human Factors, 1961, 2 (4), 203-210.

Graybiel, A. & Clark, B. Perception of the horizontal or vertical with head upright, on the side, and inverted under static conditions and during exposure to centripetal force. USN School of Aviation Medicine, NASA Joint Research Report, 1961.

Guilford, J. P. Psychometric Methods, (2nd ed.). New York: McGraw-Hill, 1954.

Lybrand, W. A., Vaughan, W. S., Jr., & Robinson, J. P. Airport marking and lighting systems: A summary of operational tests and human factors. Arlington, Virginia: Human Sciences Research, Inc., 1959. (HSR-RR-59/6-MK)

McKelvey, R. K., Brown, G. S., & Ontiveros, R. J. Simulation comparison of three runway landing zone lighting patterns. Atlantic City: Federal Aviation Agency, Bureau of Research and Development, April 1961 (a). (Task 411-3-4R)

McKelvey, R. K., Brown, G. S., & Ontiveros, R. J. Simulator comparison of narrow gauge landing zone lighting patterns in longitudinal vs. lateral arrays. Atlantic City: Federal Aviation Agency, Bureau of Research and Development, May 1, 1961 (b). (Task 411-3-4R, Problem 1)

McKelvey, R. K. & Ontiveros, R. J. Longitudinal spacing variables in "3:2:1" patterns for touchdown zone lighting. Atlantic City: Federal Aviation Agency, Aviation Research and Development Service, Research Division, December 1961. (Task 411-3-4R, Problem 2)

Smith, A. H. Gradients of outline convergence and distortion as stimuli for slant. Canad. J. Psychol., 1956, 10, (4), 211-218.

Smith, Sidney, L. Angular estimation. J. Appl. Psychol., 1962, 46 (4), 240-246.

Spencer, J. Judgment of height by the apparent obliquity of familiar ground outlines. Flying Personnel Research Committee, Report No. 819, March 1953.

Thouless, R. H. Phenomenal regression to the real object. Brit. J. Psychol., 1931, 21, 339-359.

Vaughan, W. S., Jr., Luce, T. S., & Kassebaum, R. G. Airport marking and lighting systems: A survey of operational tests and human factors, 1959-1961. Arlington, Vriginia: Human Sciences Research, Inc., 1962. (HSR-RR-61/13-MK-X)

Virnelson, T. R. & Vaughan, W. S., Jr. Heliport lighting design solutions to pilot information requirements. Arlington, Virginia: Human Sciences Research, Inc., 1961. (HSR-RR-61/17-MK-X)

APPENDIX A

ABILITY OF OBSERVERS TO ADJUST GEOMETRIC FORMS AND LINEAR STIMULI TO VARIOUS SLANT ANGLES

ABILITY OF OBSERVERS TO ADJUST GEOMETRIC FORMS AND LINEAR STIMULI TO VARIOUS SLANT ANGLES

N. W. Weissman
R. G. Kassebaum
W. S. Vaughan, Jr.

HSR-RR-61/13-MK-X

May 1962

Prepared Under:

Contract No. FAA/BRD-401
Project No. 424-2R

Systems Research and Development Service
Federal Aviation Agency
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

Prepared By:

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard
Arlington 1, Virginia

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABILITY OF OBSERVERS TO ADJUST GEOMETRIC FORMS AND LINEAR STIMULI TO VARIOUS SLANT ANGLES

I. Abstract

Two experiments were conducted to determine if any of six basic geometric designs (square, triangle, hexagon, circle, trapezoid, and rectangle) yield differential information regarding angular change. No significant differences were found; and, as a consequence, a third experiment was conducted to study subject sensitivity to angular change on the basis of the distance between elements (points) of top and bottom borders. The results of this experiment suggest that separations between the two point sources of 9-49 minutes of visual angle yield most accurate judgments of slant. Separations between point sources of less than 9 or greater than 49, yield less accuracy in estimating slant. A retinal angle of three minutes separation between the point sources appeared to fuse to a single point which yielded very little information about slant.

II. Introduction

During the final approach and landing of a helicopter, the pilot is required to make a series of complex judgments about the spatial and temporal relationships between the helicopter and the ground. He must track a glide slope and a line of flight, and control his rate of closure with a projected hover or touchdown point. One of the more difficult of his judgments is that of vertical displacement from a desired glide slope. The desired approach angle will, in the specific case, be determined by air temperature, power, and gross weight of the helicopter, restraints imposed by terrain obstacles and traffic regulations of the heliport. Given a specific set of conditions, however, the pilot will attempt to establish a certain descent angle and maintain it throughout the approach.

The helicopter pilot's information about angle of approach is derived from sources external to the cockpit. One of these sources is the outline of the heliport. Since the heliport boundary is larger than any of its other components, it is usually visible to the pilot at considerable range. As he approaches, other aspects of the marking and lighting then become available for guidance.

The perceived shape of the heliport boundary will change with changes in range and altitude; but at any given point it will have a particular apparent shape. In the design of the heliport boundary lighting or marking, therefore, the sensitivity of slant information provided by the pattern should be an important consideration since the pilot could then more sensitively judge vertical displacement from a desired angle of approach.

The purpose of the series of experiments described in this report was to investigate the ability of people to discriminate changes in perspective of a variety of geometric patterns. Should some geometric forms be found to encode this change information more sensitively than others, the former shapes should be preferred for heliport boundary lighting or marking.

III. Comparison of Six Geometric Designs by a Method of Simultaneous Presentation

Procedures

Several geometric designs have been used or suggested as outlines of landing zones for helicopter operations (Virnelson and Vaughan, 1961). Six of these designs were selected for study: square, rectangle, circle, triangle, hexagon, and trapezoid (see Figure 1). The size of the square design was scaled 1 inch equal to 10 feet to represent a 150' by 150' heliport viewed at a range of 1440 feet. The remaining five designs were equated to the square on the basis of perimeter. All geometric designs were constructed with a 60 inch length of string 1/16 inch in diameter. The strings were painted with yellow ultraviolet paint and mounted on 21 inch square cuts of black felt and illuminated by a 15 watt ultraviolet fluorescent bulb. The purpose of this particular way of presenting the designs was to reduce, as much as possible, all visual stimulation except the designs under study (see Figures 2 and 3). Two identical stimulus boards were prepared for each of the six geometric designs - one board to be used as a standard and the second to be manipulated by the subject. Stimulus boards were mounted so they could be rotated about the horizontal axis perpendicular to the line of sight at the center of the geometric design.

Twelve HSR employees, male and female, participated as subjects. Each subject was dark adapted for 30 minutes and instructed in the task required of him. The subject was seated 144 inches from the stimulus boards. Each of the six designs was presented at each of six standard angles (5, 15, 25, 35, 45, and 55 degrees from the ground plane).

FIGURE 1

Relative Sizes Of The Six Designs Used In Experiments A and B

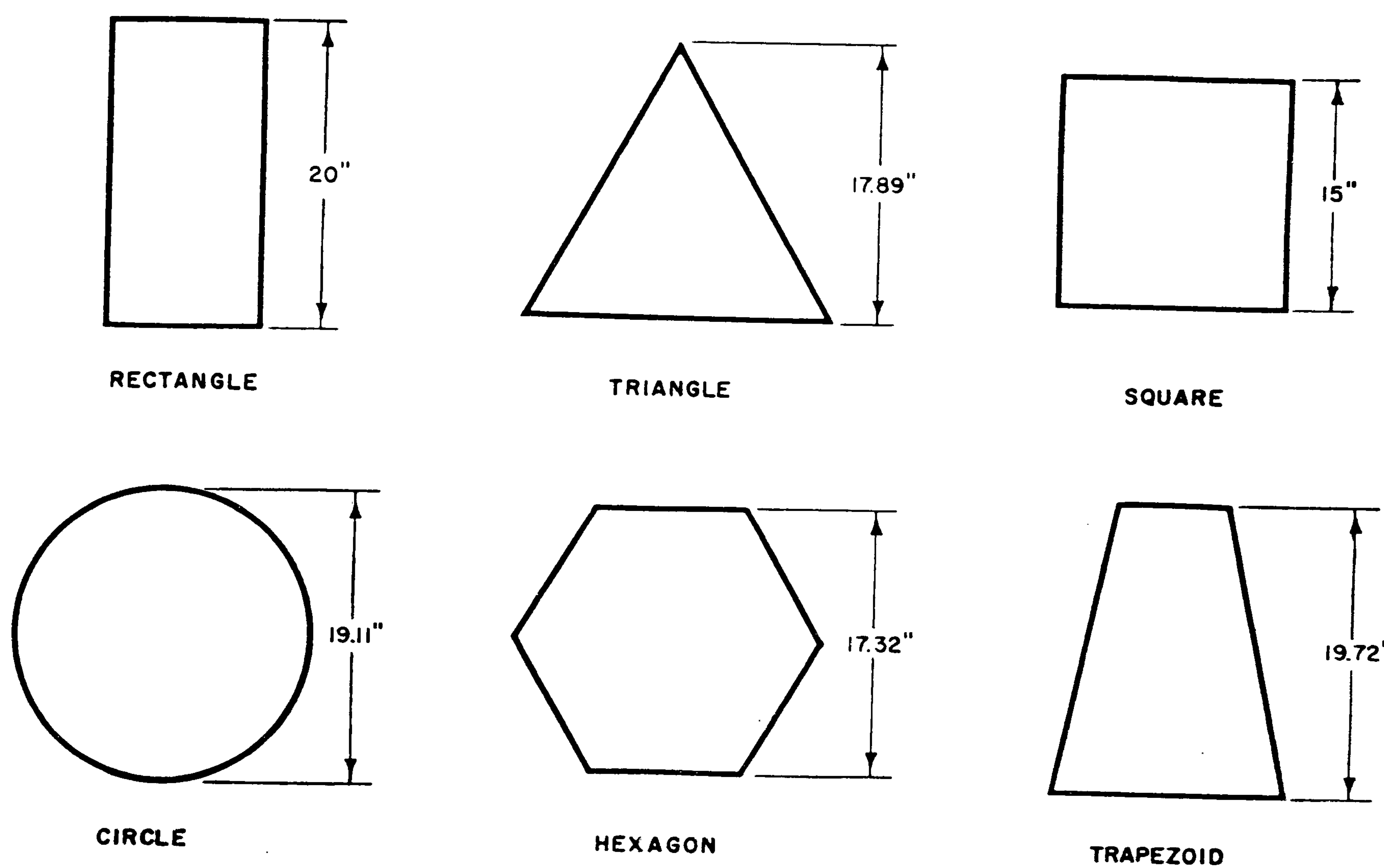
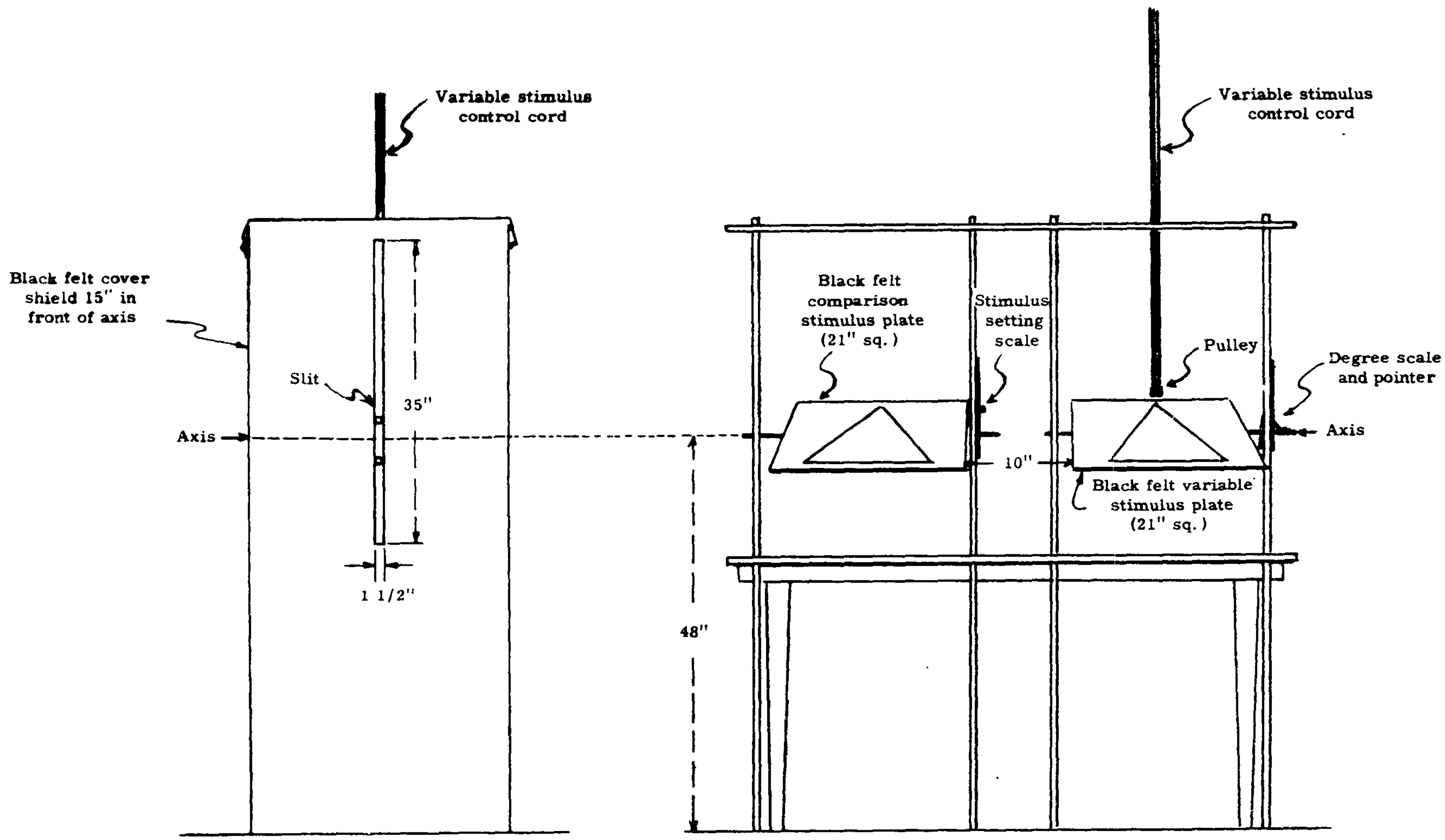


FIGURE 2

Subject View of the Angle-Plane Apparatus

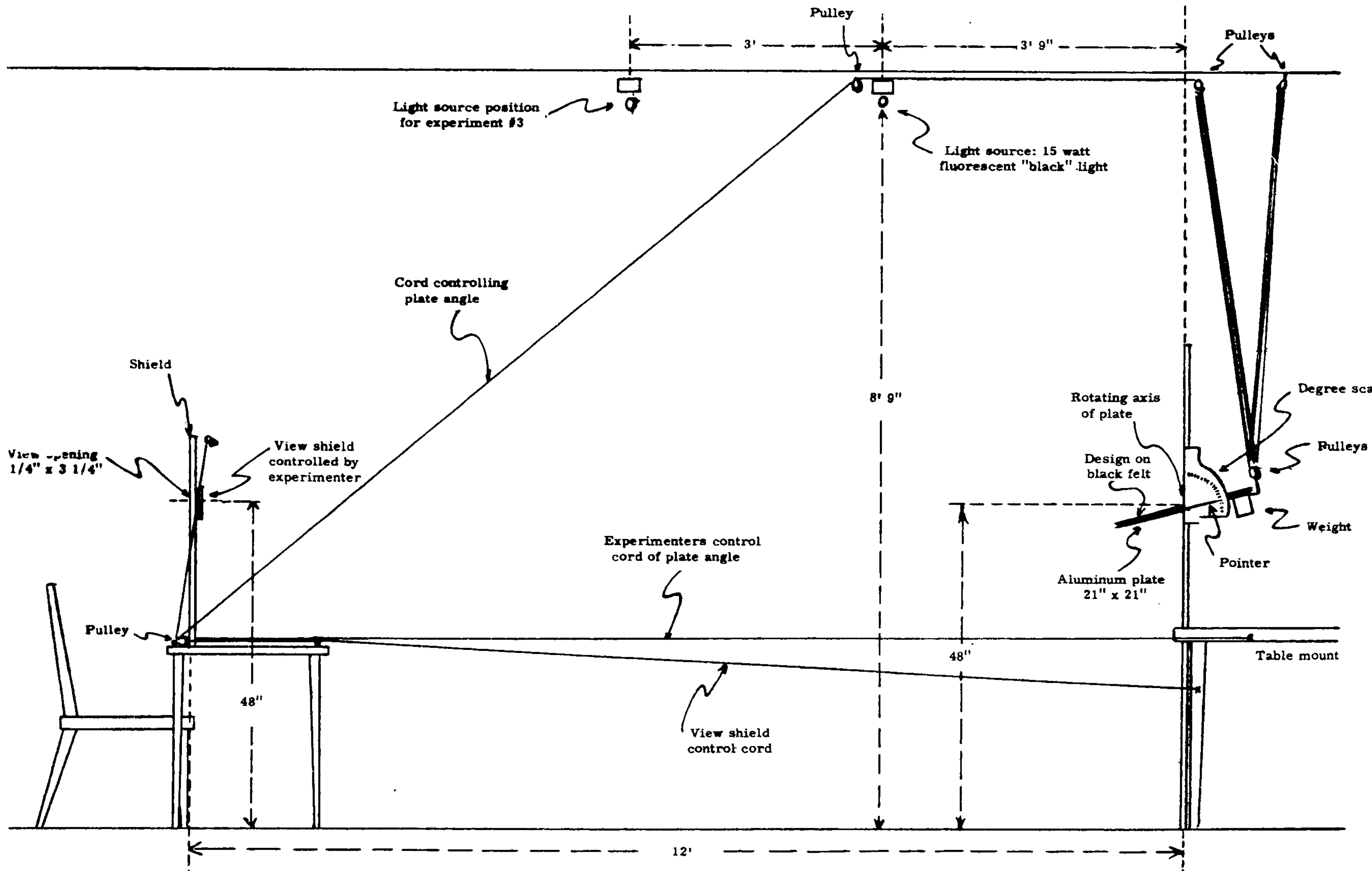


Variable stimulus shielded by felt for experiment "C"

Comparison and variable stimuli.

FIGURE 3

Dimensions of the Angle-Plane Apparatus and Subject Position



Seventy-two trials per subject were conducted since two adjustments of the variable stimulus to match the standard stimulus were required of the subject for each form at each slant angle.

On each trial the standard was set at one of the six slant angles and the variable stimulus was oriented either perpendicular or parallel to the subject's line of sight. The subject was then asked to set the variable stimulus board so as to match the standard with respect to perspective (see Figure 2). When the subject was satisfied that he had matched the slant of the standard design, he so reported to the experimenter who then recorded the selected angle to the nearest 1/4 degree.

Results

A two-way analysis of variance was performed on the error scores and significant differences ($P < .05$) among patterns and among angles were found. Bartlett's test for homogeneity of variance in the error scores was satisfied. Mean error scores for the six designs ranged from 1.0035 to 1.4913 degrees and although the overall analysis of variance suggested significant differences, no significant differences between any pair of mean scores could be detected by either Duncan (1952) or Tukey (1949) tests.

Mean error scores among the six angles ranged from .4844 to 2.0382 degrees. Lower error scores were associated with the shallower angles; higher error scores with the more perpendicular angles. Tukey's test of significance within the set of angles studied yielded a significant gap (Z test) between 5 and 25 degrees and a significant straggler (T test) at 55 degrees. The Duncan test showed significant mean differences between 5 and 25 degrees and between 35 and 55 degrees. No significant differences were found between 15, 25, 35, and 45 degrees. These results are summarized in Table 1.

TABLE 1

Significant Differences Among the Slant Angles
Indicated by the Tukey and Duncan Tests

Slant Angle (degrees)	Mean Error (degrees)		
	Tukey		Duncan
5		0.4844	
	Gap →		
25		1.1528	
15		1.1944	
35		1.4184	
45		1.4340	
55	Straggler →	2.0382	

IV. Comparison of Six Geometric Designs by a Method of Successive Presentation

Procedures

As a check on the affect of the experimental method on the resulting data of the first experiment, an essentially similar experimental design was run with a successive rather than a simultaneous presentation of variable and standard stimuli. Since in the first experiment slant angles of 15, 25, 35, and 45 degrees were not different with respect to accuracy of slant judgments, three rather than six slants were included: 5, 15, and 55 degrees. The total number of trials per subject was therefore reduced from 72 to 36. The standard stimulus was presented at one of the three slant angles for 10 seconds, then returned to a parallel position. The subject's task was to set the variable stimulus board to the angle of the standard as he recalled it. In all other respects, procedures were comparable to those used in the first experiment.

Results

An analysis of variance was not performed on the data because of the narrow error range for the six geometric designs: 2.1111 to 2.8403 degrees. As in the first experiment, the mean error scores increased with slant angle as shown in Table 2.

TABLE 2

Mean Error Resulting from Successive Presentation of the Six Geometric Designs for Three Slant Angles

Slant Angle (degrees)	Mean Error (degrees)
5	1.0816
15	2.0729
55	4.2708

V. Judgment of Slant as a Function of Separation Between Two Point Sources

It was concluded from the previous experiments that each of the six geometric designs contained sufficient information to permit equally accurate judgments of slant. The minimum design element required for judgments of slant and common to all geometric forms studied, appeared to be provided by two point sources in the vertical plane. Each design contained an upper and lower boundary separated by relatively similar distances. This variable, the separation between two points in the vertical plane, was examined in this third experiment.

Procedures

The stimuli were two 1/8 inch diameter spherical pinheads painted yellow ultraviolet. Nine pairs of pinheads were set at nine different separations ranging from 1/2 inch to 20 inches. The separation of the pairs of pinheads, the retinal angle they subtended and the mean error associated with each when set at 15 degrees slant and viewed from twelve feet are shown in Table 3. The scaling of the laboratory designs to distances on the ground was 1" = 10 feet. With this scale, the 1/8" diameter pinheads represented light sources of approximately 1-1/2 feet in diameter. The greatest distance between the pinheads used was 20" which would represent 200 feet on the ground and the smallest distance between pinheads was 1/2 inch which represents 5 feet on the ground.

In order to further reduce cues of angle, the entire visual field was draped with black felt in which a slit 3/4 inch wide and 35 inches long was cut to make the pins visible (see Figure 2). The stimulus board with pins mounted was presented to the subjects at 15 degrees slant for 10 seconds.

The view shield was then lowered and the experimenter moved the stimulus to a viewing angle of 5, 10, 20, or 35 degrees. The shield was raised and the subject adjusted the variable stimulus to match the initial 15 degrees setting. The order of distance between the pinheads and the angles from which the stimulus was adjusted were randomized and counter-balanced among ten subjects.

Results

The results are illustrated in Table 3 and Figure 4. Ability of observers to judge slant appears to be related to the separation between the point sources used to represent a minimum lighting pattern for heliports. Ability to match a given slant angle is a U-shaped function of separation. At the larger and smaller separations (greater than 49 and less than 9 minutes of visual angle) performance variability is significantly greater than when the stimuli are separated by a distance within the range 9-49 minutes.

F-tests were conducted with all pairs of variances and an .05 level of significance was used as a definition of a difference. Results of these tests are presented in Table 4. All separations connected by a line are <u>not</u> different with respect to variance in judgments of slant.

TABLE 3

Separation Between Point Sources and Variability in Judgment of Slant

Separation Between Point Sources		Variance in Judgments of Slant
(inches)	(visual angle)	($1/8^{\circ}$)
1/2	3	41.04
1	6	23.37
1-1/2	9	13.27
2	12	11.48
3	19	12.86
4	25	18.40
8	49	17.94
16	99	24.29
20	124	36.65

FIGURE 4

Variability in Judgment of Slant as a Function of Separation Between Two Point Sources

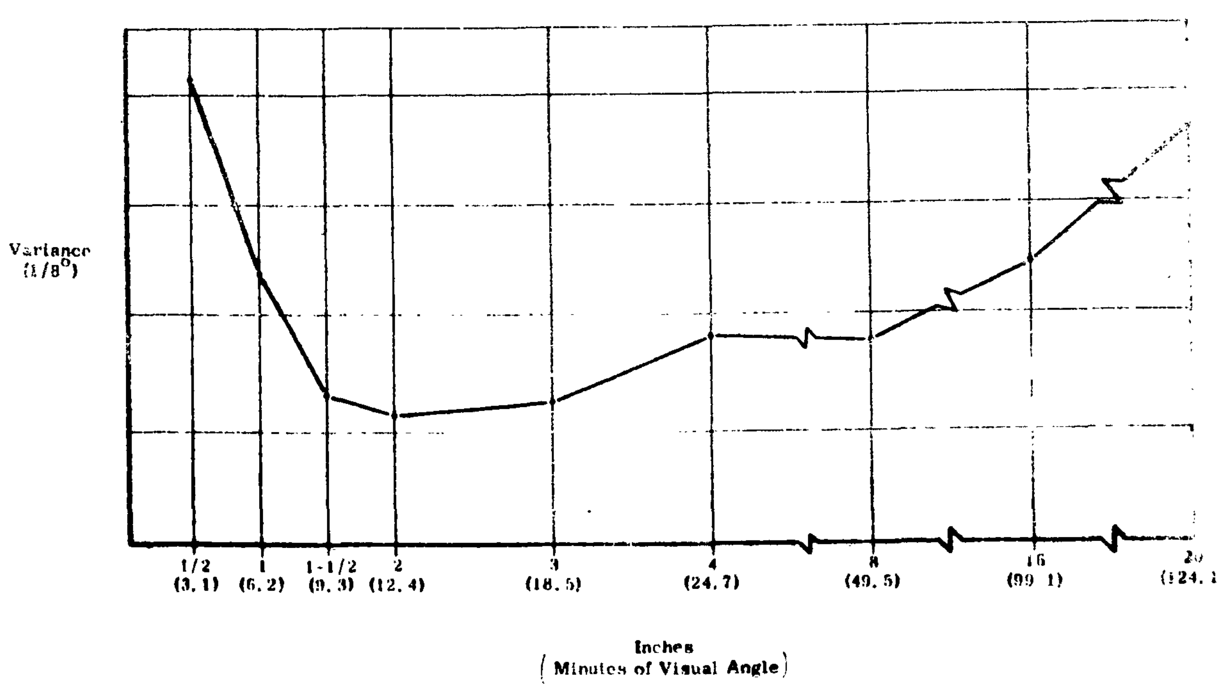


TABLE 4

Summary of F-Tests Among Pairs of Stimuli
(Multiple Range Presentation)

Visual Angle (Minutes)								
3.1	124.4	99.1	6.2	24.7	49.5	9.3	18.5	12.4

VI. Design Implications

On the basis of these results, a recommendation regarding heliport design is suggested. The relatively accurate judgments found between 9 and 49 minutes of arc suggest that a heliport design should contain lights or marks separated by a visual angle in this range throughout the final approach. Pattern elements so placed will provide the pilot with the maximum amount of information with respect to displacement in the vertical plane. This recommendation is only tentative since results were obtained in a static laboratory study under highly controlled conditions. Further verification in a flight test or flight simulation context would be required prior to a recommendation for actual heliport design practice.

VII. References

Duncan, D. B. A significance test for differences between ranked treatments in an analysis of variance. Va. J. Science, 1952, 3, 49-67.

Duncan, D. B. Multiple range and multiple F tests. Biometrics, 1955, 11, 1-42.

Smith, A. H. Gradients of outline convergence and distortion as stimuli for slant. Canad. J. Psychol., 1956, 10 (4), 211-218.

Tukey, J. W. Comparing individual means in the analysis of variance. Biometrics, 1945, 5, 99-114.

Virnelson, T. R. & Vaughan, W. S., Jr. Heliport lighting design solutions to pilot information requirements. Arlington, Va.: Human Sciences Research, Inc., December 1961. (HSR-RR-61/17-Mk-X, Contract No. FAA/BRD-401).

DATA TABLES

TABLE A: Variable stimulus settings expressed as absolute difference from the comparison stimulus. Settings for each design, starting position and subject for Experiment A

Angle	Subject	Rectangle		Triangle		Square		Trapezoid		Circle		Hexagon	
		Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
05°	1	.75	.00	1.50	.75	.25	.25	.25	.25	.75	.50	.25	.75
	2	.00	.00	.50	.75	1.00	.25	.50	.50	.25	.25	.50	.25
	3	.00	.25	.00	.00	.00	.75	1.25	.50	.00	.00	.00	.25
	4	2.00	1.75	.25	.75	1.00	.75	1.25	.00	.25	1.75	4.00	.75
	5	.25	.25	.25	.00	.00	.75	.25	.25	.25	.25	.00	.00
	6	1.50	1.50	.25	1.50	2.00	.00	.25	.25	.50	.25	.75	1.00
	7	1.00	1.00	.25	.50	.00	.25	.75	.00	.25	.75	.50	.75
	8	1.50	1.00	.50	.00	.25	.75	.00	.25	.50	.00	.25	.50
	9	.75	.25	.50	.25	.25	.50	.00	.25	.75	.75	.75	.50
	10	.00	.50	.25	.75	.25	.25	.75	.75	.25	.50	.25	.25
	11	.25	.25	.50	.00	.25	.00	1.25	.75	.00	.25	1.25	.75
	12	.25	.25	.50	.00	.25	.75	.00	.50	.25	.50	.00	1.00
15°	1	.75	.75	.75	2.00	2.25	1.75	1.50	1.50	1.75	1.50	.50	1.75
	2	1.50	.75	.25	.00	.50	1.25	1.75	1.00	2.00	2.25	.25	1.00
	3	.50	1.50	.00	.00	1.25	2.50	1.50	.00	1.25	.25	.75	1.25
	4	.25	.25	1.00	.25	2.00	2.25	.50	1.50	.25	.00	.75	.00
	5	.00	.25	.25	.00	.50	.75	1.00	.25	1.00	1.75	1.00	.75
	6	1.75	.50	4.50	.00	2.00	.50	.50	2.50	3.50	1.25	3.75	2.25
	7	1.25	.25	1.25	2.25	1.25	1.00	.00	1.00	3.00	2.50	.50	1.00
	8	1.75	1.00	1.50	1.00	.75	.75	1.25	2.00	1.75	2.25	1.25	.00
	9	.75	1.00	.25	1.25	.75	1.50	1.50	1.75	.00	1.25	.00	1.25
	10	1.65	1.25	.50	2.50	.50	3.25	1.50	1.75	.25	.50	1.25	.75
	11	1.75	1.50	2.25	2.25	2.25	2.00	1.25	3.50	1.50	3.25	.00	2.25
	12	2.25	1.50	1.00	.00	5.00	.25	.50	.75	2.75	.50	.50	.25

TABLE A (Cont.)

Angle	Subject	Rectangle		Triangle		Square		Trapezoid		Circle		Hexagon	
		Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
25°	1	.75	.75	.50	1.75	1.00	2.25	1.00	1.25	.25	.50	.50	1.50
	2	1.25	3.50	2.00	.50	.25	.50	2.00	2.25	1.00	2.00	1.25	1.25
	3	.75	.50	.25	.00	.50	1.75	1.25	1.75	.50	.25	.25	1.25
	4	1.25	1.25	.00	.00	3.00	.25	.50	.75	4.00	.25	7.00	3.50
	5	1.25	1.00	.25	.25	.75	1.00	1.00	.25	.50	.25	.00	.50
	6	1.50	5.00	0.00	.75	.25	2.25	1.25	3.25	2.75	4.25	2.50	.75
	7	1.00	.50	1.25	1.25	.50	.00	.00	.50	2.50	3.50	1.50	.75
	8	1.00	2.00	0.25	1.00	.50	.75	1.00	.00	.75	.75	3.25	.50
	9	.25	.00	.50	.50	.25	1.25	.50	1.50	.50	.75	.00	2.00
	10	.50	.75	.50	.50	.00	2.25	1.75	2.75	3.00	3.75	.50	1.50
	11	1.50	1.75	.50	1.00	2.50	.25	.25	1.25	.50	.50	1.75	1.50
	12	1.75	.50	2.00	1.50	1.00	.50	1.00	.75	.50	1.00	.00	.50
35°	1	1.00	.25	.50	1.25	.25	1.75	1.00	.25	.00	.75	.50	1.25
	2	.75	2.25	1.00	2.75	.50	2.00	1.50	1.50	.75	1.00	1.75	1.50
	3	1.00	1.00	.00	.00	.00	1.00	1.75	2.00	1.75	1.50	2.50	.75
	4	2.25	.75	.25	2.25	4.25	4.25	1.75	1.50	4.00	.50	5.25	1.75
	5	1.75	4.25	3.50	1.25	.50	.00	1.00	.50	.50	.75	1.75	1.00
	6	2.75	1.25	1.75	5.25	1.25	3.25	3.00	2.00	2.75	.75	1.50	.50
	7	.75	1.25	2.00	1.50	.50	.00	1.25	.50	.75	3.75	.75	.50
	8	.25	1.00	4.25	.25	1.50	1.50	4.50	2.75	2.75	2.00	.50	1.50
	9	.75	.00	.50	.50	1.25	2.50	1.00	.25	1.50	.25	.25	.25
	10	3.00	1.50	.00	.25	1.50	.25	2.75	3.25	1.00	1.25	.75	1.00
	11	1.25	2.00	1.25	.50	1.50	1.75	.00	2.25	2.00	1.50	.75	2.25
	12	1.50	.25	2.25	.25	.25	.50	.75	1.75	1.50	1.25	3.00	1.50

TABLE A (Cont.)

Angle	Subject	Rectangle		Triangle		Square		Trapezoid		Circle		Hexagon	
		Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
45°	1	.25	.75	.25	.75	1.25	2.00	.50	1.75	1.25	.50	.50	.50
	2	3.50	1.75	.75	.25	1.00	1.25	1.75	3.75	.75	.50	.25	2.50
	3	.50	1.00	1.50	.25	1.00	.50	1.00	2.50	1.00	.50	3.00	.50
	4	.50	1.75	.75	1.25	1.00	2.25	1.00	.75	2.75	1.75	3.50	4.75
	5	1.00	2.25	2.50	3.25	1.00	.75	4.00	.25	.50	2.25	3.00	1.75
	6	2.75	1.75	2.75	4.00	1.25	5.00	3.00	1.25	3.00	4.50	3.75	.75
	7	1.50	.50	1.00	2.00	1.75	1.75	1.50	1.00	.50	.25	.50	1.00
	8	1.50	.50	1.25	.75	.50	1.50	2.75	1.75	3.50	1.50	2.50	2.50
	9	.50	.25	1.00	.50	3.00	.75	1.00	.75	1.75	2.25	2.75	1.50
	10	.25	1.75	.50	1.75	.00	1.75	.75	.25	1.00	1.25	4.00	.50
	11	.25	1.25	.75	.75	.50	.50	2.25	.25	2.50	.75	.00	.50
	12	.00	.50	.00	.25	1.00	.75	1.00	1.00	3.75	2.50	1.00	.50
55°	1	1.00	.75	1.25	1.25	5.00	2.50	1.25	.25	.50	.75	.00	2.00
	2	2.00	2.25	.75	.50	2.75	.25	3.75	3.25	1.25	.25	4.25	.50
	3	.00	2.00	1.50	.50	2.50	3.50	.75	1.50	.75	.75	.50	.50
	4	.25	.25	.75	2.25	3.50	4.00	2.75	4.00	6.75	.50	2.00	3.75
	5	3.75	1.25	1.25	.25	1.00	.25	.50	4.50	2.25	1.50	2.00	1.25
	6	2.00	3.50	1.50	.75	4.50	1.75	.50	1.50	6.25	5.00	5.50	3.00
	7	1.00	1.25	.50	2.25	1.50	5.25	1.25	1.25	1.75	1.50	1.75	2.25
	8	1.00	1.75	2.50	2.25	.50	1.00	1.50	2.75	2.75	.75	8.50	6.50
	9	1.00	1.00	1.75	.75	.75	3.50	1.00	2.00	2.50	2.75	1.50	.00
	10	1.25	.25	1.25	3.00	1.25	2.25	1.50	3.50	3.00	3.75	4.25	3.25
	11	2.00	1.50	1.50	2.00	3.75	3.00	.00	5.25	2.25	.25	5.25	5.00
	12	4.00	2.00	.75	.25	2.50	1.50	.25	2.75	.50	4.50	1.00	2.25

TABLE B: Variable stimulus settings expressed as absolute difference from the comparison stimulus settings for three angles, each design, starting position and subject for Experiment B

Angle	Subject	Rectangle		Triangle		Square		Trapezoid		Circle		Hexagon	
		Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
05°	1	3.25	2.00	1.00	2.00	1.00	0.25	4.00	.50	.75	4.50	0.75	0.00
	2	0.25	0.75	0.00	0.75	1.75	0.25	0.00	0.25	0.75	0.00	0.25	0.00
	3	0.25	1.25	0.75	0.75	1.00	2.00	1.00	1.00	0.50	0.00	0.50	0.00
	4	1.00	2.50	0.50	0.25	0.75	0.50	1.00	1.25	1.00	0.00	0.25	0.00
	5	0.00	.75	.50	.25	1.75	0.00	.25	2.50	1.25	1.25	2.25	3.00
	6	1.25	0.75	0.75	0.50	0.25	0.00	1.00	0.00	1.25	0.00	.50	0.00
	7	0.25	1.25	2.00	1.50	2.25	3.75	1.75	0.50	3.00	3.00	2.75	1.50
	8	0.00	3.00	.50	.50	2.25	.50	3.50	4.00	0.00	1.00	.50	.50
	9	.50	1.00	.25	.50	2.00	.75	.50	1.00	1.50	0.50	1.00	.75
	10	0.25	0.25	1.00	1.00	0.50	1.25	1.50	1.75	5.00	0.50	1.25	1.25
	11	0.50	0.50	1.00	1.00	0.50	1.50	1.00	0.00	0.50	0.50	0.00	1.25
	12	2.00	2.75	0.75	0.75	7.00	2.50	1.00	0.25	0.00	1.75	0.25	0.00
15°	1	3.25	1.65	4.50	4.25	4.75	2.25	4.75	1.75	6.25	4.25	3.25	1.75
	2	1.75	4.00	1.50	0.25	0.50	1.00	1.75	0.50	0.00	2.00	0.75	2.50
	3	1.50	0.75	2.25	1.50	2.25	1.25	2.25	0.50	2.25	1.50	2.25	1.50
	4	2.00	3.75	2.00	2.50	0.00	1.00	1.50	1.25	0.25	2.50	3.25	2.00
	5	2.00	.25	2.25	3.50	1.00	0.00	4.75	.50	3.25	3.00	8.00	1.25
	6	1.00	1.50	0.00	1.75	0.50	4.00	0.50	0.50	4.00	3.00	2.00	1.50
	7	1.25	1.25	0.25	0.50	3.50	4.00	2.75	1.25	3.00	1.25	0.25	2.75
	8	2.00	1.00	2.75	.50	1.50	2 00	2.00	2.00	1.00	.75	1.00	1.75
	9	1.50	1.00	1.75	3.00	5.00	4.25	.25	.50	1.00	1.25	5.00	1.25
	10	3.50	1.75	2.50	3.50	0.50	0.75	2.00	1.75	3.75	0.25	2.25	1.75
	11	4.75	1.00	3.75	1.75	2.75	0.50	0.00	2.50	3.00	0.25	3.00	0.50
	12	3.75	4.00	3.75	6.25	3.50	0.75	0.00	5.75	1.00	0.75	1.50	1.50

TABLE B (Cont.)

Angle	Subject	Rectangle		Triangle		Square		Trapezoid		Circle		Hexagon	
		Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
55^{o}	1	1.00	1.00	1.75	10.00	3.00	4.75	4.25	20.00	4.50	1.50	7.25	2.50
	2	10.00	5.25	11.25	7.25	6.50	2.75	7.75	3.00	3.00	6.00	7.00	6.25
	3	2.25	1.25	3.75	0.00	1.75	2.50	0.50	3.00	5.00	1.75	5.00	1.75
	4	1.50	1.75	2.00	0.50	3.25	3.50	7.00	7.50	7.75	1.75	5.75	1.75
	5	4.25	.25	1.25	4.75	7.00	2.75	3.50	3.25	2.75	6.75	6.75	4.00
	6	4.75	4.25	1.75	0.75	0.75	0.25	2.50	4.50	3.25	4.75	6.75	1.75
	7	0.75	0.75	10.50	9.00	7.75	1.00	15.75	4.00	13.00	8.25	2.25	3.25
	8	12.00	3.50	1.25	5.00	10.00	.75	2.75	3.00	5.00	1.50	1.00	4.25
	9	1.00	2.75	3.75	2.00	0.00	1.25	3.25	5.75	1.25	6.00	3.50	3.75
	10	3.75	2.00	4.25	8.75	5.75	1.00	3.00	6.00	7.75	2.25	5.00	1.75
	11	1.50	1.75	3.50	7.00	4.75	2.50	8.25	12.00	2.50	2.00	4.00	4.75
	12	0.75	6.50	3.75	2.00	7.00	2.50	2.00	1.75	10.00	9.00	4.00	6.25

TABLE C: Variable stimulus setting expressed as absolute difference from the comparison setting of 15° for each dot separation and subject for Experiment C

Subject	Angle	1/2"	1"	1 1/2"	2"	3"	4"	8"	16"	20"
1	5°	0.00	3.00	1.75	1.00	3.50	0.25	1.50	0.75	1.75
	10°	1.50	1.25	0.25	1.50	0.50	2.75	0.25	0.25	0.50
	20°	0.00	.25	0.75	0.00	0.50	4.50	.75	0.00	0.25
	25°	0.50	2.00	1.00	1.00	1.50	0.25	2.00	0.50	3.50
2	5°	2.00	0.00	2.25	1.00	1.00	4.00	4.50	5.25	2.50
	10°	3.50	2.50	1.75	2.00	0.00	1.00	1.00	2.00	2.00
	20°	.75	1.75	.75	1.75	0.00	1.00	0.00	2.00	4.75
	25°	1.50	2.25	1.50	3.50	0.25	.75	2.50	9.25	0.50
3	5°	12.00	1.50	2.25	1.25	1.00	3.00	3.25	1.75	1.50
	10°	2.00	6.00	1.25	C.00	1.50	.25	1.75	.50	1.25
	20°	6.00	.75	1.25	0.75	2.50	.50	6.75	.75	2.00
	25°	5.50	2.50	.50	4.00	0.50	.25	6.25	4.50	1.75
4	5°	2.50	1.50	.50	1.25	1.50	.50	1.00	1.50	3.25
	10°	1.50	3.50	4.00	1.50	2.00	.00	0.00	.50	1.00
	20°	4.50	1.25	1.00	1.00	0.50	1.25	0.00	1.75	.25
	25°	2.25	3.00	.50	2.25	1.00	1.50	3.00	2.00	2.50
5	5°	4.50	4.00	.75	0.25	2.25	1.50	3.75	4.75	6.00
	10°	4.00	4.00	4.00	0.25	1.00	1.25	2.50	2.25	1.00
	20°	2.00	.25	2.75	1.50	1.00	4.50	1.75	7.75	.25
	25°	4.00	4.75	3.00	1.75	1.25	3.75	2.75	5.25	2.75

TABLE C (Cont.)

Subject	Angle	1/2"	1"	1 1/2"	2"	3"	4"	8"	16"	20"
6	5^{o}	1.25	.00	1.25	0.25	3.00	1.25	1.50	2.75	.25
	10^{o}	.25	.00	.75	1.00	0.50	.50	2.00	.75	1.50
	20^{o}	.25	1.50	2.00	0.75	0.50	1.25	1.75	1.50	.00
	25^{o}	.75	3.25	1.00	1.25	1.50	2.50	0.00	.75	4.25
7	5^{o}	1.50	4.25	1.25	2.25	2.75	.75	.25	.25	2.00
	10^{o}	3.25	1.25	.00	0.00	2.00	.25	.25	2.50	2.25
	20^{o}	8.75	2.00	1.75	2.50	2.50	2.25	.50	1.50	0.00
	25^{o}	7.25	.75	2.50	3.00	2.00	.75	1.25	1.00	0.50
8	5^{o}	0.00	2.00	0.50	0.75	0.00	2.50	3.25	3.00	3.75
	10^{o}	3.00	.25	0.25	3.50	1.75	5.25	1.25	1.25	10.00
	20^{o}	0.50	3.25	1.00	0.50	5.50	1.00	2.25	2.75	1.25
	25^{o}	1.00	1.25	3.75	3.25	2.50	1.75	2.25	1.75	1.50
9	5^{o}	4.50	1.00	0.00	1.00	2.50	1.25	1.00	1.50	0.50
	10^{o}	4.50	1.50	0.00	1.75	1.50	1.00	0.75	0.25	0.50
	20^{o}	3.75	2.00	0.25	1.75	1.00	1.50	2.00	0.75	1.25
	25^{o}	0.00	2.00	0.50	0.75	1.25	1.25	2.25	1.00	1.25
10	5^{o}	2.25	1.25	2.50	1.75	3.00	0.00	4.50	2.00	4.50
	10^{o}	1.25	1.00	1.50	2.75	0.00	0.75	2.50	0.50	2.50
	20^{o}	0.25	2.00	0.25	0.00	2.00	2.75	0.25	0.00	4.00
	25^{o}	2.50	5.00	4.50	1.75	0.50	2.75	0.25	1.00	1.50

APPENDIX B

ABILITY OF OBSERVERS TO ALIGN WITH LINEAR STIMULI

ABILITY OF OBSERVERS TO ALIGN WITH LINEAR STIMULI

Terrence S. Luce
R. G. Kassebaum
W. S. Vaughan, Jr.

HSR-RR-62/9-MK-X

December 1962

Prepared Under:

Contract No. FAA/BRD-401
Project No. 424-2R

Systems Research and Development Service
Federal Aviation Agency
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

Prepared By:

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard
Arlington 1, Virginia

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABILITY OF OBSERVERS TO ALIGN WITH LINEAR STIMULI

I. Abstract

Two laboratory experiments were conducted to assess human performance in aligning with linear stimuli. In the first experiment, two point sources of illumination separated by a range of distances were used as stimuli, and the subject's task was to align himself with the directional orientation of the pair of "dots". In the second experiment, solid lines of different lengths were used as stimuli and the subject's task was to align himself with the directional orientation of the line. Both experiments were conducted in a completely darkened room with the stimuli illuminated by an ultraviolet light.

Results indicate that ability to align oneself with a line or with an imaginary line defined by two dots is a monotonic function of the length of the line and of the degree of separation between the two dots. Variability of alignment responses decreased sharply as the separation between dots was increased from 2.7 to 9.1 minutes of visual angle. Beyond 9.1 minutes, alignment response variability decreased only slightly but continuously to the limit of the separation interval studied (120.6 minutes).

The function relating alignment response variability to length of line was generally similar to that for degree of separation between two dots. A sharp decrease in variability of alignment performance accompanied an increase in the length of line from 2.7 to 18.1 minutes of visual angle. Beyond 18.1 minutes, response variability decreased slightly but continuously to the limit of the variable studied (60.3 minutes).

These results have potential application to the problem of designing optimal marking and lighting patterns to provide pilots with alignment guidance.

II. Introduction

One of the pilot's control tasks during approach and landing is to maintain a line-of-flight colinear with a desired line-of-flight. In the fixed wing case, the desired line-of-flight is the extended runway centerline. In the rotary wing case, the desired line-of-flight is a radial extending downwind from the touchdown zone. The design of most airports and heliports includes some marking and lighting element to provide the pilot with a ground reference for his control task. Reviews of marking and lighting designs currently in use for heliports (Virnelson 1961) and airports (Lybrand 1959, Vaughan 1961) reveal that the principal design element for providing line-of-flight guidance is a single string of lights or a stripe mark indicating the approach centerline. The pilot's visual/perceptual task, therefore, is to judge degree of misalignment with the centerline referent, so that maneuvers can be made to correct deviations. This is essentially a compensatory tracking task (see Technical Note 2, The Nature of the Pilot's Task in Lybrand 1959).

A design question now arises as to the length of the line (marking) or interval between point sources (lighting) required to provide adequate alignment guidance. An efficient marking and lighting design element for alignment guidance is one which provides operationally effective guidance at minimum cost. Adding more lights to a centerline string or lengthening a center stripe marking may increase installation and maintenance costs without necessarily increasing operational effectiveness.

Two experiments were conducted to investigate this design problem. The purpose of the first experiment was to determine the consistency with which subjects could align themselves with an imaginary line connecting two point sources of illumination separated by different distances. The purpose of the second experiment was to describe the consistency with which observers could align themselves with a line as a function of its length.

III. Apparatus

The two experiments were conducted in a completely blackened room in order to eliminate all visual cues except the variables under study. Two round-headed map pins were mounted on a black felt-covered board and secured onto a turntable which could be rotated to any desired angle in the horizontal plane. The turntable was mounted on a stable platform secured to the floor and the display area was surrounded by black felt to reduce light to a minimum. The heads of the pins were painted with yellow ultraviolet paint and were illuminated by a 15-watt ultraviolet bulb. The bulb was encased in cardboard baffling to eliminate extraneous light. A semi-circular panel with a 2-inch viewing slot at eye level was constructed at a radius of twelve and one-half feet from the display platform (see Figure 2). The viewing angle in the vertical plane from the slot to the display platform was 15^{o}. A subject could align himself with the two illuminated pin heads, "dots", by moving laterally behind the panel until he was "lined up". Due to the semi-circular construction of the panel, the subject was at a constant distance from the stimulus regardless of his location. A scale, printed along the inside of the panel above the eye slot, allowed the experimenter to measure the subject's alignment in $1/8^{o}$ discrepancies from the angular orientation of the stimulus.

An angular scale calibrated in degrees was secured to the horizontal surface of the platform and a pointer was attached to the turntable. A radius on this scale, which, if extended, would have intersected the viewing panel near one end, was arbitrarily called zero degrees. A surveyor's level was placed midway between the stimulus platform and the viewing panel. The level was aligned with the zero radius. The level was then swung through 180^{o} and a mark sighted on the panel. This mark was called zero degrees to correspond with the zero radius. The level was then positioned over the center of the stimulus platform scale. Using the zero mark on the panel as a base, a scale was laid off by sighting through the level. Half-degree marks were added with the level. Eighth-degree marks were then added with a measuring rod. Figures 1 and 2 are illustrations of the apparatus.

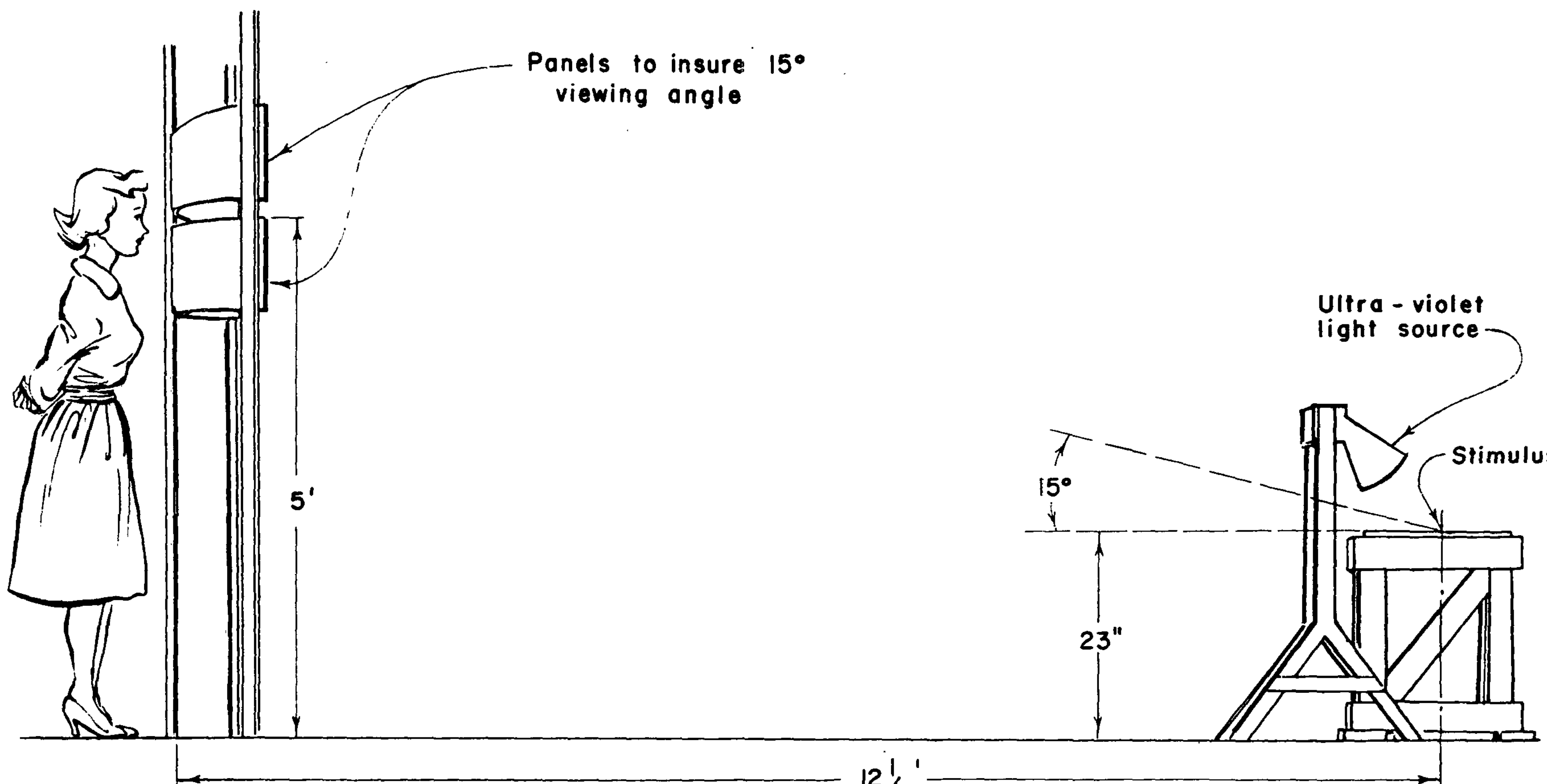


Figure 1 : Side View Sketch of Subject's Relation to Stimulus

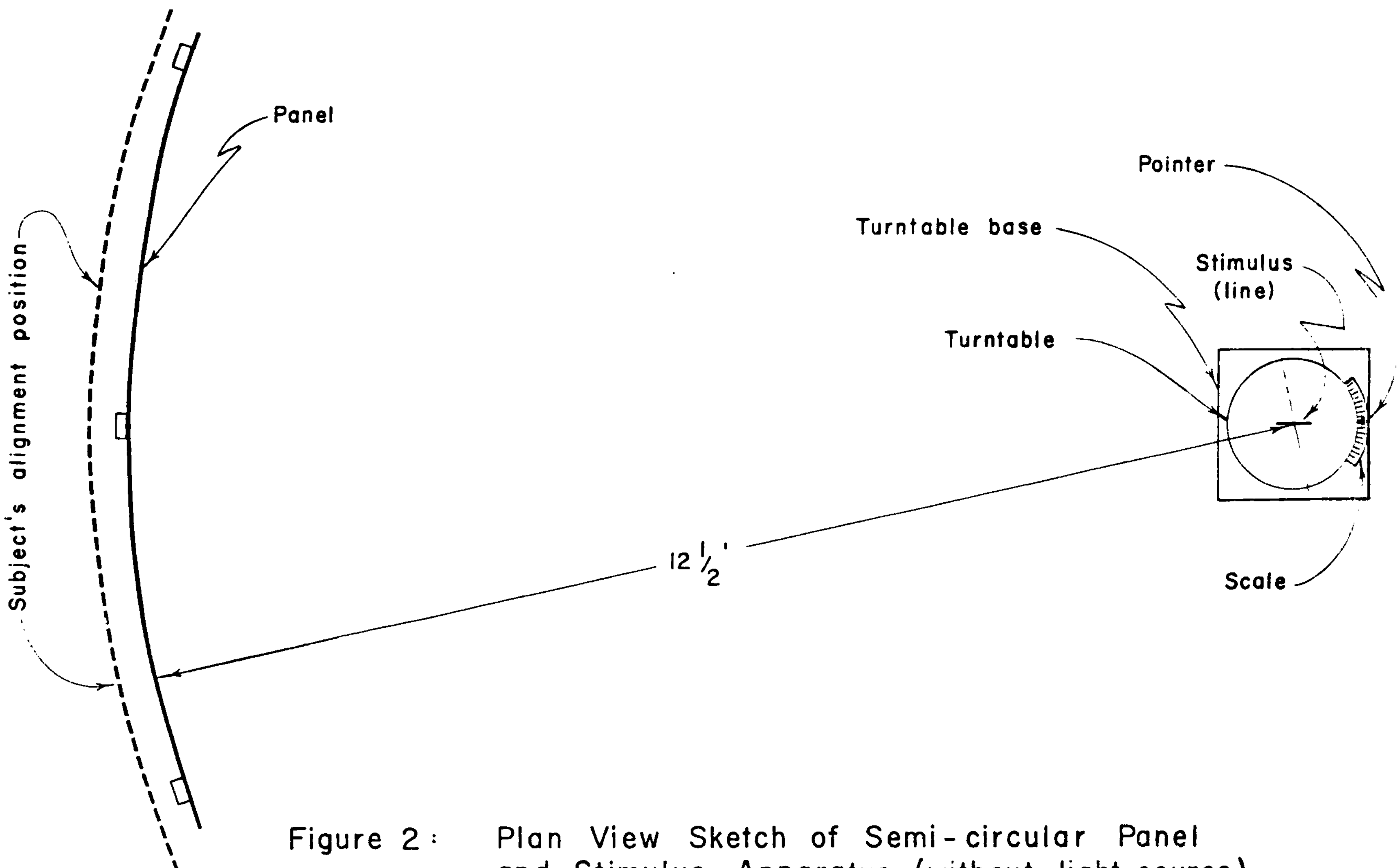


Figure 2: Plan View Sketch of Semi-circular Panel and Stimulus Apparatus (without light source)

IV. Alignment Ability as a Function of Separation Between Two Point Sources

Procedures

Fifteen HSR employees, male and female, served as subjects. Each subject was dark-adapted for 20 minutes and instructed in the task required of him. The subject was instructed to align himself with an imaginary line projected through the two dots by moving laterally behind the panel. He was then to indicate verbally to the experimenter that he was aligned with the stimulus.

Six different separations of the two point sources were studied. Each of the six stimuli was presented in six different angular positions in the horizontal plane, in a pre-determined random order. Experimental sessions, therefore, consisted of 36 trials. A seventh stimulus (20" separation between dots) was examined at the conclusion of the study.

The experimental sessions were conducted as follows: One experimenter changed the stimulus boards and set the turntable to an angular position according to the stimulus presentation plan. A second experimenter recorded the subject's position. When the subject announced that he was aligned with the dots, he closed his eyes and the experimenter used a red-filtered flashlight to illuminate the location of the subject's eyes with respect to the scale. Scale readings were taken using the bridge of the subject's nose as the reference point. Response data were analyzed in $1/8^{\circ}$ deviations from each subject's mean response to each stimulus length.

Results

Ability of observers to align with linear visual stimuli was hypothesized to be a function of stimulus extent. Table 1 presents variability of alignment response scores (in variance form) associated with each of the seven stimuli. It can be seen from the table that performance variability decreased as the separation between pairs of "dots" increased. Variability in performance decreased sharply as the "dot" separation increased from 2.7 to 9.1 minutes of visual angle. Beyond 9.1 minutes, performance variability continued to decrease gradually to 120.6 minutes - the limit of the experimental variable studied.

An F_{max} test (Walker & Lev, 1953) of significance of variance differences was performed. The results of this test indicate that the differences among the experimental conditions in alignment performance were statistically significant. Individual F tests were then made for all pairs of variances. The results of all F tests are presented in Table 2 according to Duncan (1955) so that each comparison can be readily examined. Table 2 is interpreted in the following manner. Any two experimental conditions which are <u>not</u> underscored by the <u>same</u> line are significantly different. Any two experimental conditions which are underscored by the same line are not significantly different.

Since each of the stimuli had been presented six times, once at each of six different scale positions, an F_{max} test was conducted for position bias in the response variability data. Table 3 presents a summary of this test which indicates that differences in the variability of alignment responses are not related to the directions in which the stimuli were oriented.

TABLE 1

Variability of Alignment Response
to Separated Dots

Dot Separation		Variance
(inches)	(visual angle)	$(1/8^{o})^2$
1/2	2.7	49.48
3/4	4.5	29.78
1 1/2	9.1	13.22
3	18.1	10.91
6	36.2	8.11
10	60.3	7.26
20	120.6	5.27

TABLE 2

F Test (Multiple Range Presentation) for
Significance of Differences Among Dot Separation
in Alignment Response Variability

Visual Angle (Minutes)						
2.7	4.5	9.1	18.1	36.2	60.3	120.6

TABLE 3

F_{max} Test for Position Affect on Alignment Response Variability

	Variance	F_{max}	Significance Level
Variance Max.	14.36	1.17	Not Significant
Variance Min.	12.24		

V. Alignment Ability as a Function of Line Length

Procedures

Ten HSR employees, male and female, participated as subjects in this second experiment. Eight of them had been subjects in the first study. The experimental apparatus and procedures were identical to those of the first experiment except that straight line stimuli were substituted for the dot stimuli. Sections of wire 1/8 inch in diameter were mounted on black felt-covered boards in lengths corresponding to the dot separations, i.e., 1/2", 3/4", 1-1/2", 3", 6" and 10". The wire was painted with yellow ultraviolet paint and illuminated as in the previous study.

Results

Table 4 presents the variances in alignment response for each of the stimulus conditions. As had been the case with separated dots, response variability decreased systematically as line length increased. An F_{max} test was made and the results indicate significant differences among the stimuli with respect to variability in alignment judgments. Individual F tests were then made for all pairs of variances. These results are presented in Table 5.

Alignment response variability as a function of dot separation and line length is illustrated graphically in Figure 3. Individual F tests were made for significance of variance differences between corresponding stimuli in the two experiments, i.e., 1/2 inch line lengths were compared with 1/2 inch dot separations, etc. Only the variances associated with the 1/2 inch (2.7 minutes) stimuli were significantly different. At all other visual angles studied, alignment response variability to lines and to separated dots was equivalent.

TABLE 4

Variability of Alignment Response
to Line Length

Line Length		Variance
(inches)	(visual angle)	$(1/8^{o})^{2}$
1/2	2.7	237.12
3/4	4.5	36.27
1 1/2	9.1	15.48
3	18.1	7.58
6	36.2	7.03
10	60.3	4.73

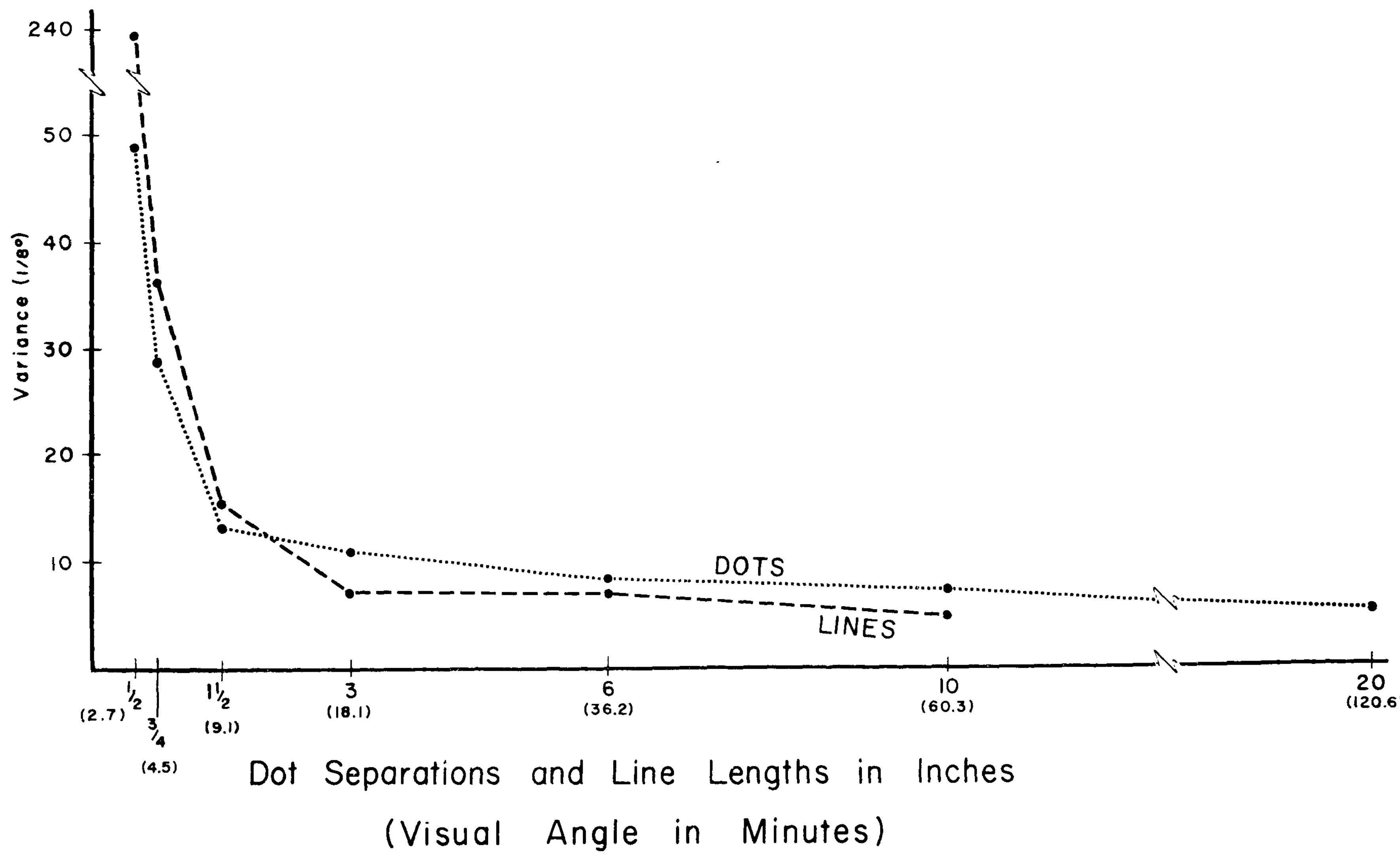
TABLE 5

F Test (Multiple Range Presentation) for
Significance of Differences Among Line Length
in Alignment Response Variability

Visual Angle (Minutes)					
2.7	4.5	9.1	18.1	36.2	60.3

Figure 3:

ALIGNMENT RESPONSE VARIABILITY AS A FUNCTION OF DOT SEPARATION AND LINE LENGTH



VI. Conclusions

The ability of observers to align themselves with simple, linear visual stimuli is a function of stimulus extent. As the length of a line is increased, alignment performance becomes less variable; as the separation between two point sources is increased, alignment performance becomes less variable.

Alignment response variability decreases sharply as the separation between pairs of dots is increased from 2.7 to 9.1 minutes of visual angle. Beyond 9.1 minutes, response variability continues to decrease slightly, but not significantly, to 120.6 minutes.

Alignment response variability decreases sharply as the length of a line is increased from 2.7 to 18.1 minutes of visual angle. Beyond 18.1 minutes, response variability continues to decrease slightly but not significantly, to 60.3 minutes.

Alignment response variability is not significantly different as a function of type of stimulus (lines or separated dots) except at 2.7 minutes of visual angle, the smallest visual angle studied. At this visual angle the variance associated with the two point sources was significantly smaller than that associated with the solid line.

VII. Design Implications

Operational generalizations from the results of this study are subject to all the qualifications of laboratory research, and much validation work in the operational situation must be done before design recommendations can be made. With this caution in view, the following implications are presented.

The results of this study suggest that a very simple linear pattern, two point sources of light aligned with the desired line of approach, is adequate to provide a pilot with alignment guidance. The point sources should be separated by at least 9.1 minutes of visual angle and can be separated by 120.6 minutes without impairing alignment guidance. If alignment guidance is provided by a solid line, it should be at least as long as required to subtent 18 minutes of visual angle.

Two point sources of light, separated by an interval equal to the length of a solid line, provide alignment guidance at least as well as the corresponding solid line, and at very small visual angles, 2.7 minutes, two separated point sources provide better guidance than does a solid line. The design implication of this finding is apparent: as economy is a consideration in the construction of a lighting configuration, one can use a pattern of separated point sources rather than a solid line of stimuli.

Since limits of the stimuli were not examined in the present study, caution should be exercised in generalizing beyond the stimulus values used. It is likely that at some separation of lights greater than 120.6 minutes, alignment performance would be degraded.

VIII. References

Duncan, D. B. Multiple range and multiple F tests. Biometrics, 1955, 11, 1-42.

Lybrand, W. A., Vaughan, W. S. Jr., & Robinson, J. P. Airport marking and lighting. Operational tests and human factors. Arlington, Va.: Human Sciences Research, Inc., May 1956. (HSR-RR-59/1-Mk, Contract No. FAA/BRD-13).

Vaughan, W. S., Jr., Luce, T. S., & Kassebaum, R. G. Airport marking and lighting systems: a survey of operational tests and human factors, 1959-1961. Arlington, Va.: Human Sciences Research, Inc., May 1962. (HSR-RR-61/13, Contract No. FAA/BRD-401).

Virnelson, T. R., & Vaughan, W. S., Jr. Heliport lighting design solutions to pilot information requirements. Arlington, Va.: Human Sciences Research, Inc., December 1961. (HSR-RR-61/17-Mk-X, Contract No. FAA/BRD-401).

Walker, H. M., & Lev, J. Statistical Inference, Henry Holt and Co., New York, 1953.

DATA TABLES

TABLE A

Deviation of Subject's Alignment Response to Dots
(Cell entries are in $1/8^{o}$)

Separation Between Dots in Inches

Subject	1/2	3/4	1 1/2	3	6	10	20
1	+19	+13	+5	+12	+17	+1	+5
	+12	+5	+7	+5	+5	+8	+7
	+9	+2	+11	+2	+10	+4	+3
	+22	+14	+9	+11	+9	+7	+4
	+8	+11	+9	+7	+7	+7	+5
	+12	+4	+8	+9	+5	+9	0
2	+12	-8	+2	+3	0	+3	
	-10	+7	+6	+3	+3	+4	
	-9	+2	+1	+8	+4	+6	
	-3	+6	+2	+8	+6	+5	
	+12	-2	+3	+8	+4	+4	
	-7	-4	0	+3	+9	+1	
3	+4	-6	-2	+1	-8	+1	-4
	+7	-2	-5	0	-2	-1	-7
	+6	-3	-3	0	+4	-4	-4
	+16	-2	-1	0	0	-4	-5
	+13	-2	-5	-3	+2	-3	-7
	+10	-2	+4	0	+2	-2	-4
4	-5	-8	0	+1	+3	+6	+3
	-1	-3	-1	-2	-5	-1	0
	-3	-8	-1	+6	-4	-3	-1
	+1	-9	-1	-2	+3	+1	+2
	-4	-15	-2	+4	+1	+2	+2
	-1	-2	-5	+2	+2	+1	0

<u>TABLE A (Cont.)</u>

	Separation Between Dots in Inches						
	1/2	3/4	1 1/2	3	6	10	20
Subject							
5	+17	-8	+7	0	+4	+5	+3
	+8	-5	+5	0	+4	-1	+4
	+7	-7	+3	+1	+1	+4	+5
	+5	-9	+5	-1	+2	-4	+3
	+16	+2	+6	+4	+5	+1	0
	-1	-5	+9	+5	+1	+5	+3
6	+6	+6	+11	0	+14	+4	
	+18	+5	+11	+6	+12	+4	
	+9	-1	+8	+10	+10	+4	
	+11	-2	+12	+8	+10	+8	
	+8	+2	+16	+10	+8	+4	
	+12	+2	+4	+10	+6	-7	
7	+5	-7	+9	0	+3	+4	
	+12	-3	+2	+3	+9	0	
	+5	+3	-2	+4	+11	+3	
	+4	+1	+4	+5	+7	+4	
	0	+3	+10	+4	+12	+5	
	+16	-5	0	+4	+9	+8	
8	+15	-2	+3	+4	+2	+2	0
	+13	+3	+7	+5	+3	+3	-1
	+7	+6	+6	+1	+2	+3	0
	+20	+5	0	+4	+5	+7	+1
	+10	+2	+1	+4	0	+4	+1
	+16	+5	+3	+7	+4	0	0

TABLE A (Cont.)

Separation Between Dots in Inches

Subject	1/2	3/4	1 1/2	3	6	10	20
9	+2	-18	-2	-1	-2	+4	+2
	+3	+5	-4	-1	+1	-5	-3
	+7	-10	+2	+3	0	-3	+1
	+5	-22	+3	+2	+5	-1	-1
	-8	-7	-7	+2	+3	-4	-4
	-3	-9	-4	-2	+1	-3	0
10	-11	-5	-6	-8	-2	-6	
	+2	-14	-8	-3	-3	-5	
	+7	-8	-7	0	-7	-1	
	+9	-8	0	-3	-3	-1	
	-10	-4	-4	-1	+4	-6	
	0	-9	-6	+1	+1	-5	
11	+28	+8	+1	+16	+10	+4	
	-13	+4	-2	+12	+10	+3	
	+12	+12	+3	+6	+10	+4	
	+12	+8	+4	+12	+10	+8	
	+25	+18	+4	+15	+10	+3	
	+20	+12	+5	+9	+4	+8	
12	-4	-16	-14	-2	-3	+5	
	-4	-14	+3	+4	-4	-1	
	+6	-2	-4	+4	-2	+3	
	-3	+13	-1	-5	-1	-4	
	-1	-6	+8	-3	-4	-1	
	-22	+3	0	-6	-5	-3	

TABLE A (Cont.)

Separation Between Dots in Inches

Subject	1/2	3/4	1 1/2	3	6	10	20
13	+19	-8	+2	-1	+5	+4	
	-7	+6	+4	+6	+6	+6	
	+11	-10	+10	+8	0	+2	
	0	+3	+6	-3	+8	+10	
	+18	+4	-2	-4	+8	+8	
	+1	+8	0	+7	+5	+2	
14	+16	+5	+13	+6	+9	+8	
	+11	0	+6	+4	+11	-1	
	+1	0	+1	+8	+5	-2	
	+15	-7	+14	+5	+9	+8	
	0	0	+12	-6	+14	0	
	+12	+14	+4	-8	+17	0	
15	+8	0	-14	-4	-2	-1	-4
	+6	-5	-8	-2	-1	-3	0
	+12	+3	-8	+3	-7	-4	0
	-7	-13	+2	+5	-7	-4	-4
	+6	-12	-2	-6	0	-6	-2
	+2	-2	-9	+2	-3	-5	-4
16							-8
							-8
							-5
							-6
							-4
							-2

TABLE A (Cont.)

	Separation Between Dots in Inches						
Subject	1/2	3/4	1 1/2	3	6	10	20
17							-8
							-9
							-10
							-8
							-7
							-11
18							-6
							-7
							-4
							-6
							-6
							-4

TABLE B

Deviation of Subject's Alignment Response to Lines
(Cell entries are in $1/8^{o}$)

Length of Line in Inches

Subject	1/2	3/4	1 1/2	3	6	10
1	+24	-4	-8	+4	+6	-6
	+16	-4	-14	-3	+4	0
	+21	0	-9	+5	0	0
	+28	+7	-4	-3	-2	-6
	+42	-7	-4	-1	+2	-8
	+48	0	-8	+5	-1	-4
2	+4	-2	-8	0	-5	-2
	-24	-4	-6	-2	-1	-2
	-33	+3	-6	0	-3	-4
	-19	-1	-4	+2	+3	+2
	-8	0	-7	-6	+1	-2
	-16	+8	-11	-1	+6	-3
3	+16	+27	+4	+10	+9	+7
	-11	+28	+7	+12	+10	+8
	+27	+12	+15	+16	+8	+7
	+24	+16	+13	+9	+9	+8
	+32	+16	+11	+16	+16	+12
	+8	+16	+15	+12	+14	+12
4	-4	+3	-6	-1	-4	-1
	-19	+6	-11	+1	0	-4
	-26	-24	-2	0	+4	-5
	+19	-1	-2	-4	+2	+1
	-12	0	-5	+6	+4	-4
	+4	-8	-3	-8	-3	-5

TABLE B (Cont.)

Length of Line in Inches

Subject	1/2	3/4	1 1/2	3	6	10
5	-22	-6	-8	+2	-5	+2
	+7	-18	-4	-1	-4	+2
	-14	-12	-12	-2	+2	+4
	-14	-15	-5	0	-2	0
	+20	-5	-12	+1	0	+4
	+4	-5	-8	-2	0	+2
6	+24	-2	-5	+3	-1	+2
	-4	+5	-3	+4	-1	+1
	-12	+5	0	+2	0	+3
	-4	-4	-3	+2	+1	+1
	-12	-5	0	0	+2	-1
	+15	-8	-2	+2	+3	0
7	-8	0	-20	-2	-6	-5
	-11	-9	-18	-2	-3	-5
	+6	-14	-17	-2	-2	-4
	+4	-20	-12	-5	-4	-7
	-2	-15	-12	-2	-4	-6
	+3	-15	-14	-5	-5	-6
8	+2	-4	+6	+10	+11	+12
	+1	-6	+1	+5	+14	+10
	+3	+1	+8	+8	+9	+4
	+4	0	+15	+2	+8	+10
	-8	-6	+2	+4	+12	+8
	+4	-6	+6	+6	+10	+8

TABLE B (Cont.)

	Length of Line in Inches					
	1/2	3/4	1 1/2	3	6	10
Subject						
9	+50	+4	-5	+9	+10	+4
	+34	+24	+8	+8	+6	+11
	+68	+9	+7	+2	+3	+10
	+35	+17	-6	+2	+8	+7
	+58	+8	+7	+9	+2	+4
	+46	+4	0	+5	+11	+8
10	-11	-10	-12	+6	0	-4
	-3	-14	+2	-3	0	0
	-36	+2	-6	+4	0	+1
	-28	-7	+4	+2	-6	-4
	+42	+3	+4	+6	+4	+2
	+50	0	-5	+5	+2	+2

APPENDIX C

ABILITY OF OBSERVERS TO ADJUST LINEAR STIMULI TO A HORIZONTAL ORIENTATION

ABILITY OF OBSERVERS TO ADJUST LINEAR STIMULI TO A HORIZONTAL ORIENTATION

Wallace F. Rollins
W. S. Vaughan, Jr.

HSR-RR-63/2-MK-X

February 1963

Prepared Under:

Contract No. FAA/BRD-401
Project No. 424-2R

Systems Research and Development Service
Federal Aviation Agency
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

Prepared By:

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard
Arlington 1, Virginia

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABILITY OF OBSERVERS TO ADJUST LINEAR STIMULI TO A HORIZONTAL ORIENTATION

I. Abstract

Two laboratory experiments were conducted to assess human performance in adjusting linear stimuli to a horizontal position. In the first experiment, solid lines of various lengths were used as stimuli and, in the second experiment, the stimuli were pairs of "dots" separated by various intervals. In both studies the subject's task was to adjust the stimulus to a horizontal position. The experiments were conducted in a completely darkened room with the stimuli illuminated by an ultraviolet light.

Results indicate that ability to adjust linear stimuli to the horizontal is a function of stimulus extent. Response variability decreased as line length increased to 132.6 minutes of visual angle. Variability increased, then decreased again to its former level when longer line stimuli were presented. As the separation between dots increased, variability decreased to a minimum at a separation of 221. 4 minutes of visual angle. When the separation was increased beyond this point, variability increased significantly. At four of the seven stimulus extents studied, response variability was significantly less when dots were used as stimuli than when lines were used.

These results have potential application to the problem of designing optimal marking and lighting patterns to provide pilots with roll guidance.

II. Introduction

The helicopter pilot, during the final approach, must carefully control the rotational movement of his aircraft about its longitudinal axis, i.e., his roll attitude. In order to maintain his aircraft in a level attitude (or whatever degree of roll is necessary to compensate for crosswind or drift from course), the pilot needs an informational basis on which to estimate his moment-to-moment deviations from the level attitude. One source of such information is the artificial horizon on the instrument panel but this is of limited usefulness during a VFR landing and during the final phase of an IFR landing when the pilot is attending primarily to extra-cockpit stimuli. The most obvious extra-cockpit source of this type of information is the real horizon but this too has its shortcomings. For one thing, it is not always visible. In addition, its use requires a shift of focus on the part of the pilot and the magnitude of this shift increases as the more critical (i.e., closer to the ground) phases of the landing are approached. What is needed is a horizontal reference in the immediate vicinity of the intended touchdown spot.

Most heliport lighting designs in current use include a reference of this sort. These elements can be of two general types: either an illuminated bar or a line defined by two or more lights and placed perpendicular to the desired line-of-flight. Although the horizon reference has been generally accepted as a useful design element for roll guidance there seems to have been relatively little consistency with respect to the length of line or interval between lights required for optimal guidance.[1]

[1] Virnelson, T. R. and Vaughan, W. S., Jr. Heliport Lighting Design Solutions to Pilot Information Requirements. Arlington, Va.: Human Sciences Research, Inc., December 1961. (HSR-RR-61/17-MK-X, Contract No. FAA/BRD-401)

Two experiments were conducted to investigate this design problem; namely, the relationship between consistency of judgments of the horizontal and line length or interval between lights. The purpose of the first experiment was to determine the consistency with which subjects can adjust an illuminated line to the horizontal as a function of the length of the line. The second experiment differed only in that the independent variable was the distance separating two point sources of illumination.

III. Apparatus

The experiments were conducted in a completely blackened room in order to eliminate all visual stimuli except those under study. Line stimuli were made of 1/8 inch diameter wire, painted with yellow ultra-violet paint, and mounted on small panels which were covered with black felt. The panels were secured to a larger felt-covered display platform which could be rotated about its longitudinal axis by the subject by means of a string-and-pulley arrangement. The stimuli were illuminated by a 15-watt ultraviolet bulb which was encased in cardboard baffling to eliminate extraneous light. A vertical panel with a viewing slot at eye level was erected at a distance of 12-1/2 feet from the display platform. The edges of the viewing slot were irregular in order to eliminate a possible horizontal reference which might aid the subject in adjusting the stimulus to the horizontal. The viewing angle in the vertical plane from the slot to the display platform was 15 degrees. Figure 1 is an illustration of the apparatus.

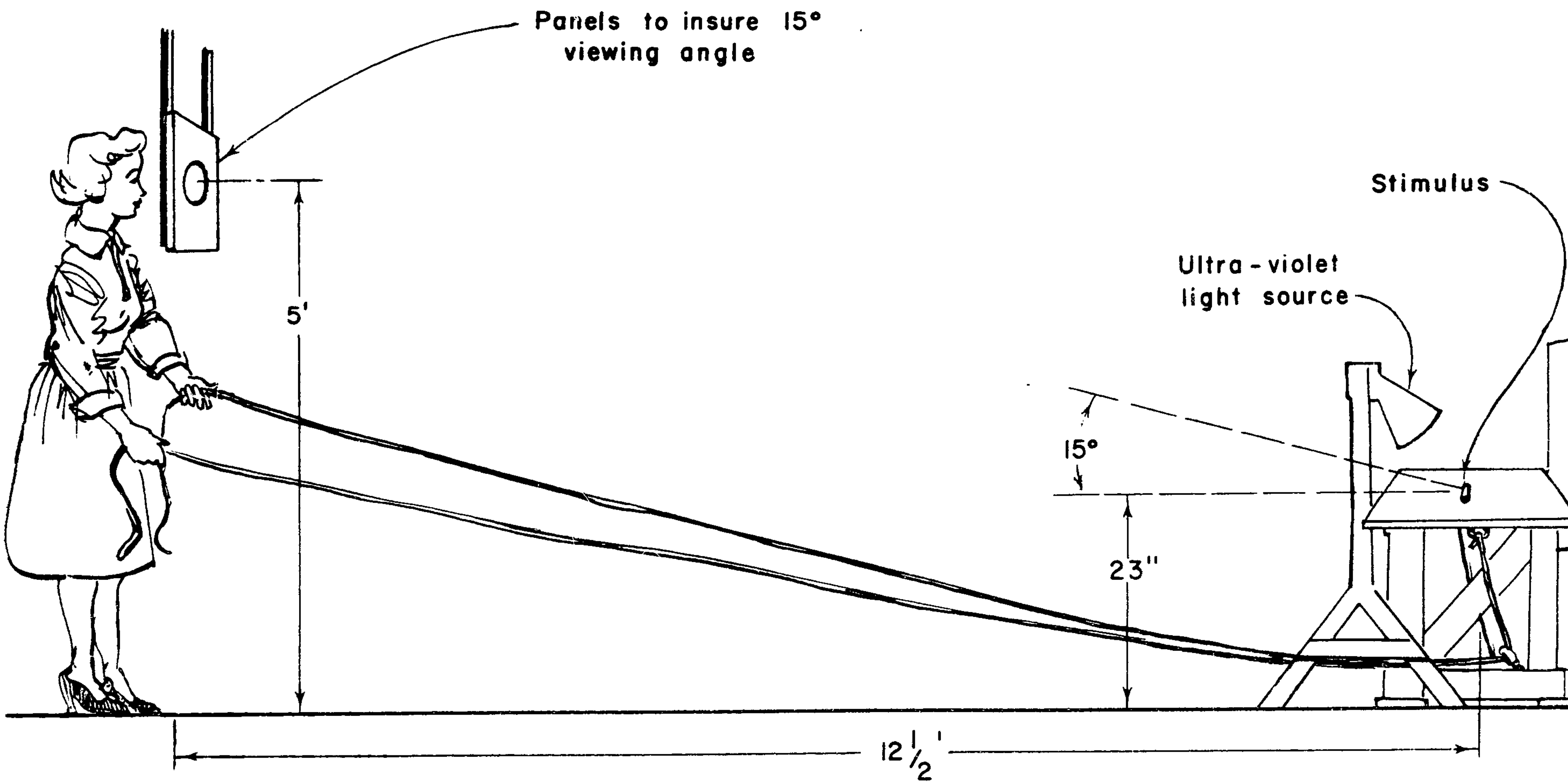


Figure 1: Side View Sketch of Subject's Relation to Stimulus

IV. Consistency of Judgments of the Horizontal as a Function of Line Length

Procedures

Fifteen HSR employees, male and female, served as subjects. Each subject was dark-adapted for 20 minutes and instructed in the task required of him. The subject was instructed to adjust the stimulus line to the horizontal by pulling on the strings. He was then to indicate verbally to the experimenter that the final adjustment was made.

Seven different line lengths were studied. Each subject made six adjustments with each of the lines for a total of 42 trials. On each trial the experimenter offset the display platform from the horizontal, alternating left and right, and the subject adjusted it back to the horizontal. The experimenter took the reading, to the nearest 1/8 degree, from a protractor-type scale mounted on the end of the rod about which the platform rotated. A red-filtered flashlight was used by the experimenter in order to read the scale. Data were analyzed in $1/8^{o}$ deviations from each subject's mean response to each line length.

Results

The consistency with which observers are able to adjust linear visual stimuli to the horizontal was hypothesized to be a function of stimulus extent. Response variabilities (variances) associated with each of the seven line lengths are presented in Table 1. An F_{max} test (Table 2) of the variances revealed significant differences. Individual F tests were then calculated for all pairs of variances. These values are presented in Table 3. Examination of Table 1 indicates that variability in performance decreased as the length

of the line increased with one reversal at 221.4 minutes of visual angle. Variability decreased sharply from 11 minutes to 33.3 minutes, less sharply but still significantly from 33.3 to 132.6 minutes, increased significantly from 132.6 to 221.4 minutes, and decreased significantly from 221.4 to 442 minutes. The difference between the variance associated with the 132.6 minute line and that associated with the 442 minute line is not significant (see Figure 2 for a graphic presentation of the results).

TABLE 1

Response Variability as a Function of Line Length

Line Length		Variance of Judgments of the Horizontal (degrees)
Inches	Minutes of Visual Angle	
1/2	11.0	4.809
3/4	16.6	4.272
1-1/2	33.3	1.447
3	66.4	.929
6	132.6	.598
10	221.4	.988
20	442.0	.449

TABLE 2

F_{max} Test for Differences Among Line Lengths in Response Variability

	Variance	F_{max}	Significance Level
Variance Max.	4.809	10.71	Beyond .01
Variance Min.	.449		

TABLE 3

F Tests of Significance of Difference in Response Variability Among Line Lengths*

Line Length (Minutes of Visual Angle)	16.6	33.3	66.4	132.6	221.4	442.0
11.0	1.126	3.323	5.177	8.042	4.867	10.710
16.6		2.952	4.598	7.241	4.324	9.514
33.3			1.558	2.420	1.465	3.223
66.4				1.554	1.064	2.060
132.6					1.652	1.332
221.4						2.200

*A value of 1.45 is required for significance at the .05 level.

V. Consistency of Judgments of the Horizontal as a Function of Separation Between Two Point Sources

Procedures

Fourteen HSR employees, male and female, participated as subjects in this second experiment. The apparatus and procedures were identical to those of the first experiment except that dot stimuli were substituted for the straight line stimuli. Two round-headed map pins were mounted on a black felt-covered panel and painted with yellow ultraviolet paint. There were seven such pairs of pins separated by distances corresponding to the lengths of the lines studied in the first experiment, i.e., 1/2", 3/4", 1-1/2", 3", 6", 10" and 20". The display platform was illuminated as in the first study.

Results

Table 4 contains response variabilities associated with each of the seven dot separations. An F_{max} test of the variances (Table 5) revealed significant differences. Table 6 contains F tests for all pairs of variances.

The differences between the 11 and 16.6 minute separations and between the 16.6 and 33.3 minute separations were not significant. Variability decreased significantly from the 33.3 to 66.4 minute separation. There was an insignificant increase from 66.4 to 132.6 minutes and a significant decrease from 132.6 to 221.4 minutes. Variability increased significantly from 221.4 to 442 minutes. As was the case with line stimuli, the difference between the variance associated with the 132.6 minute separation and that associated with the 442 minute separation is not significant (see Figure 2 for a graphic presentation of the results).

TABLE 4

Response Variability as a Function of Dot Separation

Dot Separation		Variance of Judgments of the Horizontal (degrees)
Inches	Minutes of Visual Angle	
1/2	11.0	1.708
3/4	16.6	1.924
1-1/2	33.3	1.774
3	66.4	.598
6	132.6	.748
10	221.4	.327
20	442.0	.570

TABLE 5

F_{max} Test for Differences Among Dot Separations in Response Variability

	Variance	F_{max}	Significance Level
Variance Max.	1.924	5.88	Beyond .01
Variance Min.	.327		

TABLE 6

F Tests of Significance of Difference in Response Variability Among Dot Separations*

Dot Separation (Minutes of Visual Angle)	16.6	33.3	66.4	132.6	221.4	442.0
11.0	1.126	1.039	2.856	2.283	5.223	2.996
16.6		1.085	3.217	2.572	5.884	3.375
33.3			2.967	2.372	5.425	3.112
66.4				1.251	1.829	1.049
132.6					2.287	1.312
221.4						1.743

*A value of 1.45 is required for significance at the .05 level.

Comparison of Lines and Dots

F tests were computed for all pairs of lines and dot separations of equal length. These results are presented in Table 7. Four of the seven values are significant and in all four cases the lower variability is associated with the dot stimuli. This occurs at 11, 16.6, 66.4 and 221.4 minutes of visual angle (see Figure 2).

TABLE 7

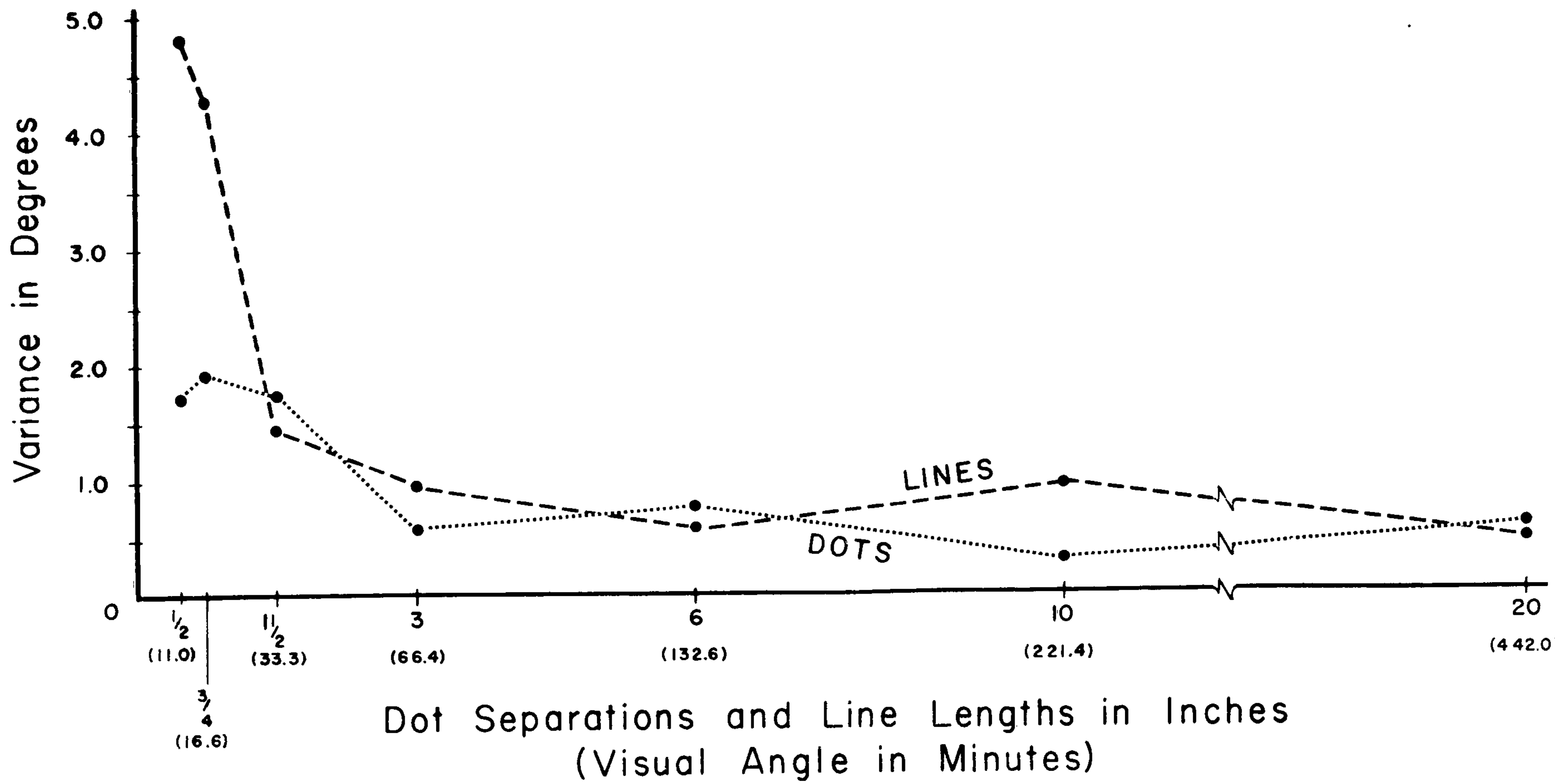
F Tests of Significance of Difference in Response Variability Between Lines and Dots of Corresponding Length

Stimulus Length (minutes of visual angle)	Variance of Responses to Lines	Variance of Responses to Dots	F*
11	4.809	1.708	2.816
16.6	4.272	1.924	2.220
33.3	1.447	1.774	1.226
66.4	.929	.598	1.554
132.6	.598	.748	1.251
221.4	.988	.327	3.021
442.0	.449	.570	1.269

*A value of 1.45 is required for significance at the .05 level.

Figure 2.

RESPONSE VARIABILITY AS A FUNCTION OF DOT SEPARATION AND LINE LENGTH



VI. Conclusions

The consistency with which subjects are able to adjust linear visual stimuli to the horizontal is a function of stimulus extent. As the separation between two point sources of light or the length of an illuminated line is increased, performance becomes less variable.

Response variability decreased sharply as the length of line was increased from 11 to 33.3 minutes of visual angle and reached a minimum at 132.6 minutes. Variability increased at 221.4 minutes and, at 442 minutes, decreased to the level associated with the line length which subtended 132.6 minutes. From these results, a line length of 132.6 minutes appears to reduce variability to an asymptotic level.

Response variability decreased as the separation between dots was increased from 11 to 221.4 minutes of visual angle. When the separation was increased to 442 minutes, variability increased significantly.

Response variability is significantly different as a function of type of stimulus (lines or dots) at four of the seven stimulus values studied. At all four points the smaller variance was associated with the dot stimuli.

VII. Design Implications

Operational generalizations from the results of this study are subject to all the qualifications of laboratory research, and much validation work in the operational situation must be done before design recommendations can be made. With this caution in view, the following implications are presented.

The results suggest that a very simple linear pattern, two point sources of light on a line perpendicular to the desired line of approach, is adequate to provide a pilot with roll guidance. Two point sources of light, separated by an interval equal to the length of a solid line, provide roll guidance at least as effectively as the corresponding solid line and, at four of the seven stimulus values studied, the point sources provided better guidance than lines of corresponding length. If, however, solid lines are to be used, they should be at least long enough to subtend a visual angle of 132.6 minutes.

The optimal separation of the two lights appears to be that distance which subtends a visual angle of approximately 3.7 degrees (221.4 minutes) at the pilot's eyes. The visual angle subtended is, of course, dependent upon the distance between the pilot and the lights as well as the distance between the lights. Lights should be placed such that the optimal visual angle is subtended when the aircraft reaches that point in the flight path where roll control is most critical. It seems likely that roll control becomes more and more critical as the helicopter approaches the landing pad and is most critical during the hover and landing phase. Therefore, taking into account the cockpit visibility characteristics of helicopters, the lights should be placed at such a distance from the touchdown point that they are clearly visible to the pilot when the aircraft is hovering over the touchdown point. They should be spaced such that, at that distance, adjacent pairs of lights subtend a 3.7 degree visual angle at the pilot's eyes. This optimal visual angle can be approximated at other points in the flight path by the use of more than two lights in the pattern.

DATA TABLES

TABLE A

Deviations of Subjects' Adjustment Responses to Lines
(Cell entries are in degrees)

	Length of Line in Inches						
	1/2	3/4	1 1/2	3	6	10	20
Subject							
1	0	+0.25	+1.75	+1.75	0	+0.50	0
	+2.00	-2.00	-0.25	0	+1.00	+1.00	-1.25
	-3.25	-0.75	+0.50	-1.00	+2.75	+1.50	0
	+0.50	+0.50	+3.25	0	+4.00	+2.25	+0.75
	+1.50	-3.50	-0.75	-0.50	-1.50	0	-1.25
	+6.00	-1.00	+3.50	+0.75	-0.75	+2.00	-1.25
2	+0.25	0	+2.00	-0.25	-0.25	-0.75	+1.50
	+0.75	+2.25	+0.50	+0.375	0	0	+1.75
	+1.00	+1.00	-0.25	-0.25	+0.25	0	+0.75
	+1.75	+1.75	+1.50	0	+0.50	+0.25	+1.25
	+2.25	+0.75	+1.50	-0.25	+0.75	+0.25	+0.50
	+1.25	-0.75	+0.50	-0.25	+0.50	-0.25	+0.75
3	-1.00	-4.25	+2.75	-0.50	+1.25	+1.00	-0.25
	-9.00	+1.00	+0.25	-0.50	+1.00	0	0
	+1.50	-2.75	+3.00	+2.00	+2.00	0	-0.50
	-1.25	-0.75	+1.75	-0.75	+0.25	-1.50	-1.25
	-1.00	-8.25	+0.25	0	+2.00	-2.00	-1.25
	-7.75	-5.25	+0.25	-0.50	+1.50	-0.50	-0.25
4	-2.25	0	-0.75	+1.50	+2.50	+2.50	+1.00
	+2.375	-1.00	-1.25	+0.50	-1.25	+3.50	+1.50
	+2.25	+2.75	+0.25	+2.25	+0.25	+3.00	+1.75
	+1.375	+3.50	0	+0.75	-1.00	+2.75	+3.50
	-1.00	+4.00	+2.75	+1.75	+0.25	+0.75	+1.50
	+2.00	+0.25	+4.00	+1.75	+0.25	+1.25	+1.75

TABLE A (Cont.)

Length of Line in Inches

Subject	1/2	3/4	1 1/2	3	6	10	20
5	+ 7.50	- 0.50	+3.75	-1.50	+0.25	0	-1.00
	+13.25	+ 3.25	-2.00	+0.25	-1.25	+1.00	+0.50
	+ 6.25	-15.75	+2.75	-3.50	-0.50	-1.00	-0.75
	- 0.50	-11.75	-0.25	-4.50	-2.50	-0.50	-1.75
	+10.00	- 7.50	-5.00	-5.50	-1.00	-0.50	-2.00
	+13.25	- 3.75	+0.50	-4.50	-1.75	-3.25	-3.75
6	+3.125	-0.50	-0.50	+1.25	0	+1.25	-0.50
	+0.25	-1.75	-1.25	+2.00	-1.50	+0.25	-0.625
	+2.00	-1.25	-1.50	-1.75	0	0	-0.875
	-0.25	-2.375	-0.75	-1.00	-0.625	+0.25	-1.125
	+2.00	-1.50	-2.00	-1.00	-1.875	+0.25	-0.625
	+4.50	-4.00	-3.25	+2.25	-3.50	0	-1.125
7	+3.00	+0.25	+1.875	-0.375	0	+0.50	-0.50
	+1.75	+1.75	+3.00	-1.00	+0.25	-0.25	+0.75
	+4.50	+1.375	+1.375	-1.375	+1.125	-0.50	+1.25
	+1.50	+1.75	+3.75	-0.75	+1.125	+1.375	+1.50
	-0.75	0	+2.00	-0.75	+1.50	0	+0.50
	-2.75	+2.25	+2.50	+0.75	+2.00	+0.75	+0.75
8	+6.00	+5.50	-0.25	+3.00	-1.00	+3.125	+3.00
	+2.375	+6.50	+2.00	+4.25	-0.50	+1.00	+1.50
	+5.25	+4.75	+4.25	0	+2.125	+2.75	+1.25
	+4.25	+4.50	+3.25	+2.75	+3.00	+3.50	+2.50
	+1.00	-0.25	+1.50	+1.625	+1.625	+2.75	+3.00
	+3.25	-0.75	+2.25	-2.00	+1.25	+0.50	+3.00

TABLE A (Cont.)

	Length of Line in Inches						
	1/2	3/4	1 1/2	3	6	10	20
Subject							
9	-0.25	-1.50	-1.25	-1.50	-2.25	-2.00	0
	+2.75	-8.25	-0.25	-0.50	-1.25	0	+0.25
	+5.00	-1.00	-2.50	+0.25	-1.50	0	-2.25
	+1.00	-3.50	+2.25	+1.25	+0.25	+0.50	-0.75
	-4.00	-1.25	-0.25	+2.00	-1.25	0	+0.25
	+6.50	-3.00	-3.50	+4.00	-1.75	+1.25	+0.25
10	+1.75	0	-3.25	+0.25	-1.875	+0.375	-1.00
	+0.50	-1.00	-0.50	0	0	-0.75	-1.25
	-0.625	-4.50	-4.00	+0.25	-1.25	-0.375	-1.75
	+0.25	-2.75	-2.50	-0.75	-0.375	-1.25	-2.25
	-3.00	-4.75	-3.75	-0.875	+0.25	0	-2.25
	+3.75	-5.25	-2.75	-0.75	+0.50	+0.25	-1.00
11	-9.00	+4.00	+2.25	+3.00	+2.375	-0.25	+1.25
	+2.75	+3.00	+3.625	+5.25	+2.375	0	+2.50
	-0.25	+4.25	+4.75	+2.00	+1.00	+7.00	+3.75
	+1.00	+2.50	+3.375	+3.00	+1.00	+0.25	+1.75
	+1.75	+2.00	+0.50	+3.50	+0.25	+4.50	+2.50
	+4.75	+2.25	+4.00	+2.50	+1.00	+2.75	+3.50
12	+1.50	+1.00	+2.50	-0.25	+0.75	+0.25	+1.375
	+1.00	-1.75	+2.00	+1.25	+0.875	+2.25	+2.25
	+1.00	+0.50	+2.25	-0.50	+1.00	+2.25	+0.75
	+0.25	+1.75	+0.75	+1.25	+1.50	+2.375	+1.50
	+2.25	-0.625	+3.875	+1.50	+0.25	+2.50	+0.625
	-2.25	-1.875	+1.50	+0.375	-1.25	+2.75	+1.25

TABLE A (Cont.)

	Length of Line in Inches						
	1/2	3/4	1 1/2	3	6	10	20
Subject							
13	-6.50	-3.375	+1.50	-0.25	-4.00	-4.00	-1.75
	-1.00	+2.00	+1.375	0	-3.875	-3.50	-4.125
	-4.50	+3.25	-0.50	+0.75	-2.75	-2.25	-2.00
	-1.75	-3.00	+0.25	-2.50	-4.25	-5.00	-2.875
	+0.50	-0.25	+0.125	-3.25	-1.75	-4.00	-2.75
	-3.25	-5.25	-1.75	-4.75	-3.75	-3.125	-5.00
14	+4.00	+5.00	-0.50	+1.25	0	-0.25	+0.125
	+6.375	-3.375	+1.00	-2.00	-1.50	-1.00	+0.50
	+0.50	+3.25	-1.00	0	-0.25	-1.75	-0.125
	-1.00	+2.25	-4.75	0	-2.00	-1.25	-0.125
	-3.75	+1.625	-2.00	-0.625	+1.00	-1.00	-0.25
	-3.75	-6.25	-2.25	-2.50	-2.50	-2.00	-0.75
15	+1.50	+4.50	+0.75	0	0	+0.50	+0.125
	-6.625	+2.00	+2.25	+2.00	-1.50	-0.25	-0.125
	+2.50	0	+1.50	-0.25	+0.75	+2.625	-1.00
	+7.00	+2.75	+5.25	-1.50	-0.25	+1.25	+0.50
	-8.00	+1.25	-0.75	+1.75	-0.125	-0.375	+1.125
	+5.00	+1.00	-2.375	-1.00	-0.50	+1.50	-0.375

TABLE B

Deviations of Subjects' Adjustment Responses to Dots
(Cell entries are in degrees)

Subject	1/2	3/4	1 1/2	3	6	10	20
	Separation Between Dots in Inches						
1	-1.00	-3.00	+1.00	0	-1.50	-1.75	-0.75
	+1.00	-2.50	+1.00	-2.00	-0.75	-1.00	+0.125
	-1.00	-2.25	+0.75	0	+0.25	-1.75	-1.00
	-3.50	-0.75	+0.50	-0.125	-1.75	-1.25	-0.50
	-2.25	-1.00	-0.75	+0.50	+0.50	-0.50	-0.75
	-1.75	-0.75	-0.25	-0.50	+1.00	+0.25	-1.25
2	+4.75	+0.25	+0.375	-1.375	+1.50	+2.00	+2.25
	+4.50	+0.25	+3.75	+1.25	+4.25	+3.00	+2.50
	+0.375	+2.00	+1.25	-1.25	+2.75	+2.25	+2.625
	-0.75	+4.75	+8.25	-2.25	+1.75	+3.00	+0.50
	-0.75	+0.875	+6.50	+1.25	+1.625	+1.75	-1.25
	0	-2.25	+5.00	+0.25	+4.50	+1.50	+2.75
3	+0.25	+0.125	+0.50	+2.25	-1.875	+0.875	+5.75
	+1.75	+0.25	+1.375	+4.25	+0.75	+2.125	+3.00
	+5.25	+0.50	+2.00	+3.25	+0.75	+1.375	+2.50
	-1.00	-0.25	+0.375	+2.25	-0.125	+0.50	+2.00
	+6.00	+0.75	+1.25	+2.00	+1.75	+2.125	+2.50
	+2.75	+2.25	+1.125	+0.875	+2.25	+1.625	+2.50
4	0	-1.00	-1.25	-2.00	-4.50	-0.50	-1.50
	-0.25	-4.00	-2.25	-0.25	-0.75	-0.875	-0.875
	-1.75	-4.50	-1.50	-2.25	-3.00	-1.125	-2.00
	-2.75	-7.00	0	-1.00	-1.00	0	-0.50
	-2.50	-2.75	+1.50	0	-2.50	-0.125	-3.00
	-2.375	-5.25	-2.00	-1.00	-1.875	-1.00	-1.00

TABLE B (Cont.)

	Separation Between Dots in Inches						
	1/2	3/4	1 1/2	3	6	10	20
Subject							
5	+1.75	-2.625	0	-1.00	0	0	-3.25
	+1.00	-2.50	-1.50	-0.50	-0.25	0	-2.00
	+2.875	-3.50	-2.25	+0.75	+0.25	+0.125	-2.50
	+1.25	-3.75	+0.75	-1.00	0	-1.00	-2.50
	+2.625	-2.50	-1.00	-0.75	+1.00	+1.00	-2.00
	-2.125	-1.75	-0.50	0	+1.375	0	-1.75
6	-1.75	+0.875	+1.00	-0.50	-2.75	-0.375	0
	+2.00	+2.00	+1.00	+0.25	-0.125	+0.25	-1.75
	-2.25	0	-2.125	-1.00	-1.875	-1.00	-2.00
	+1.75	+0.375	+3.125	+0.25	-0.50	-0.25	-0.50
	+1.00	-1.75	+2.50	0	-0.25	-1.00	-1.125
	+0.375	+1.25	+0.50	+0.25	+1.625	+0.125	-1.75
7	+0.25	-1.50	+1.00	+1.75	-1.25	+1.50	+4.00
	-0.375	-0.75	+1.00	+1.00	-1.25	+0.375	+1.875
	-1.00	-3.00	-0.50	-1.25	-0.50	+0.375	+1.75
	0	-2.25	-1.00	-0.25	+1.75	0	+0.50
	+1.875	-0.125	-1.875	+1.125	+2.50	+0.50	+2.00
	+4.00	-3.00	0	-0.25	+2.00	+0.25	+1.00
8	+1.875	-3.125	+1.25	+0.50	+0.25	-1.50	-0.75
	-1.00	-2.625	0	+1.25	0	-2.00	-0.75
	-0.25	-3.00	+0.375	+0.125	-1.00	-0.625	0
	-1.875	-0.50	+1.375	0	+1.125	+0.75	-0.25
	-1.50	-0.25	+1.00	+2.125	+0.50	-0.25	-0.25
	+0.50	-1.75	-0.25	+0.625	+0.25	-0.375	0

TABLE B (Cont.)

Subject	Separation Between Dots in Inches						
	1/2	3/4	1 1/2	3	6	10	20
9	+2.00	-5.50	+1.00	+2.00	-1.50	+0.50	-1.375
	+0.875	+2.25	0	+1.625	0	0	+2.75
	+1.00	-1.00	+1.00	-1.00	+0.625	+0.625	+2.25
	+0.625	-7.625	-1.50	+2.625	+0.25	+3.00	+1.00
	-2.125	+0.25	-1.50	0	+0.50	-0.50	-1.75
	-1.875	-0.50	0	+3.00	+1.00	+0.75	+0.25
10	+3.50	-3.50	-4.375	-1.25	+0.50	+1.75	+2.00
	-0.25	-1.75	-4.875	+3.50	0	-1.00	+0.25
	+0.50	-5.50	-0.625	+0.25	0	-1.00	+2.50
	-3.25	0	-0.125	+2.25	+0.50	-0.25	+1.875
	+5.25	-1.00	-0.625	0	-4.50	+0.625	+2.00
	+1.25	+6.50	+0.625	+0.75	-2.75	+1.50	0
11	+0.375	+1.75	+0.25	+0.50	-0.625	0	0
	+1.00	+1.25	+0.625	+0.25	0	+0.50	+0.25
	+0.25	-0.75	+0.625	+1.00	-1.125	+0.25	-0.375
	+2.75	-2.25	0	+1.25	-0.50	+1.25	+1.00
	-1.00	-2.00	+0.875	+1.125	0	+0.875	-0.50
	-0.25	-1.75	+2.50	+1.25	+0.75	0	+1.00
12	+3.75	-1.25	+1.00	0	-0.50	-2.50	+0.25
	-1.50	-2.125	+1.75	+0.25	+0.25	-1.00	-0.75
	+3.25	-3.25	+1.75	-1.00	0	-0.75	+0.25
	+1.25	-3.00	+0.75	+2.25	+2.00	-1.50	-1.00
	-1.25	+2.00	+0.50	+2.00	+0.25	-2.00	+2.25
	+4.25	-0.75	+0.25	+1.75	0	-0.50	+2.25

TABLE B (Cont.)

Subject	1/2	3/4	1 1/2	3	6	10	20
13	0	+3.75	-1.25	+1.625	+0.25	+0.375	+0.25
	+4.75	+5.00	0	+2.75	+0.25	-0.125	+1.00
	+0.625	+6.50	+2.75	+3.25	-0.75	+1.375	+1.75
	+3.00	+5.75	+2.25	+2.00	+1.00	-0.625	+0.50
	+3.875	+3.50	+2.25	+3.00	+2.00	+0.50	+1.75
	-0.25	+4.75	+7.00	+1.625	+1.50	-0.125	+1.25
14	-3.375	-3.50	-6.00	-2.25	+1.50	-2.00	-0.25
	-3.75	+1.50	+0.375	+0.375	+0.50	-1.375	0
	-0.875	-2.875	-2.50	-3.00	+0.25	+0.50	0
	-2.625	-3.625	-1.50	+0.50	+2.00	+0.25	+0.625
	-3.125	-2.00	-1.00	-2.00	+0.25	-1.00	-1.00
	-2.625	-1.375	-1.375	+1.00	+2.00	+1.25	-0.50